Distribution of The Benthic Macroinvertebrate Fauna in Northeast Thailand: Variation of Faunal Assemblages due to Environmental Changes

by

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2 April 1998

This work is dedicated to my lord Buddha
Beyond the common ever

To my mother,
To my greatest buddhist monk Boonchoop Tinnako,
Who enlighten my life

ABSTRACT

Current knowledge and understanding of freshwater ecology in tropical Asia is very limited. This thesis investigated firstly, the spatial and temporal characteristics of benthic macroinvertebrates across the monsoonal flood plain of the Pong River catchment, in northeast Thailand. Secondly, change in the benthic community was examined in terms of its sensitivity towards environmental impacts including seasonal and human impacts. Thirdly, the performance of biotic indices and scores developed for benthic communities in the temperate zone was tested. Fourthly, the utility of biological data at species or family levels, and density or binary counts in quantifying water pollution was assessed. Lastly, the study describes the small scale variation in benthic community structure in a pristine tropical forest at Phukradueng.

The benthic community varies through time and space over the study site, and was markedly related to the degree of environmental degradation. Most benthic taxa were abundant in less impacted upstream waters but declined in downstream disturbed reaches. Sensitive mayfly and caddisfly species were more diverse in less polluted than impacted waters.

The magnitude of forest loss led to high sediment yield in the water column which reduced benthic larvae colonisation. Certain caddisfly and mayfly species were especially affected by high suspended solids.

Changes in water quality due to seasonal flooding and human impacts both caused a significant decrease in taxa. The abundance of most benthic groups decreased significantly during the rainy season irrespective of the degree of human impacts. Water pollution caused by humans is more obvious during the hot season when the pollution impact gradient is clearly recovered in ordinations of the sites based on benthic larvae. Classification of sites based on benthic fauna agreed well with water chemistry results and a self-purification zone along the river was reflected in a locally increased diversity of certain taxa.

Among indices and scores tested, measures of species richness, family richness, and Ephemeroptera/Trichoptera best reflected water pollution. Of several diversity indices tested, the Shannon-Weiner index most significantly correlated to water pollution, and the biological working party score (by average score per taxon) was significantly closely correlated to organic water pollution.

Both density and presence/absence data resolved at species level gave similar results in classifying sites when analysed by multivariate methods. At family level, only density data provided a satisfactory indication of impacted and less impacted sites.

The benthic fauna in pristine headwater forests was much more diverse than in the lower catchment. Trichoptera had the greatest species richness which correlated to the extent of undisturbed forest land. The pattern of colonisation by benthic larvae in various substrates, from boulder to sand, was markedly different. The larger the substrate size, the more diverse species were found. Colonisation patterns on various nutrient-bound substrates were also found to be species specific. Benthic community structure also differed between riffle and pool areas within a site. However, the intra-site differences due to riffle and pool microhabitat is overwhelmed by larger scale habitat difference such as altered riparian vegetation types and modified ecosystems.

This study has demonstrated the feasibility of using benthic macroinvertebrates for assessing environmental impacts in a monsoonal tropical climate. These communities at small scales are related to environmental change at a site, while on a larger scale the diversity of these taxa can indicate the relative health of the freshwater ecosystem.

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CHAPTER 1

Introduction

Why choose to study benthic macroinvertebrates?

Knowledge of freshwater stream and river ecology is very limited in tropical latitudes compared to the temperate zone (Rundle et al. 1993, Dudgeon 1994b). Dudgeon (1994a, 1994b) has highlighted the urgent need for study of the inland waters of tropical Asia. Insufficient information about monsoonal freshwater ecosystems has been identified as a factor limiting the adoption of effective water resource management (Gopal and Sah 1993). This need motivated the present study which explores and analyses how macroinvertebrates are distributed and respond to varying degrees of natural and human impacts in a tropical monsoonal landscape.

It has been argued that monitoring water quality by means of chemical parameters alone has limited capacity in detecting ecosystem health (Steedman 1994). Therefore, using aquatic biota could prove to be very useful in detecting both continuous and intermittent water pollution discharges and inrecognising a state of healthy water quality (Cairns 1984, Abel 1989, Metcalfe 1989, Karr 1991, Rosenberg and Resh 1993, Steedman 1994). For example, I have monitored fish-kill phenomena almost every year in north east Thailand, but when major water chemical factors were measured at these sites, readings still complied with established water quality standards. This was generally because the causative pollutant was temporary and had already passed downstream and therefore could not be detected by chemical means.

Another factor supporting the use of macroinvertebrates is the cumulative effects of some pollutants. For example, as the tropical Pong catchment enters the hot period, an increased incidence of fish kills can be observed in some polluted stretches even though there was no contemporary discharge during that period. Under these circumstances, chemical analysis failed to detect the accumulated effects in that river reach. Therefore, I wish to discover whether biological criteria will be a more reliable method in assessing water pollution in tropical Asia as it is increasingly applied in temperate Europe and North America.

There is an increasingly large body of evidence that the benthic macroinvertebrate fauna can be an indicator for detecting local water pollution and could even respond well to larger ecosystem changes (Plafkin *et* *al.* 1989, Hilsenhoff 1987, Lenat 1988, Ohio EPA 1990, 1993, Yoder 1995, DeShon 1995). Methods and advantages of using this fauna in monitoring environmental changes have been recently compiled and reviewed by various authors (see Rosenberg and Resch 1993, Loeb and Spacies 1994, Davis and Simon 1995, and references therein). This therefore raises the question of whether this approach will also have utility in tropical latitudes.

A major impediment to this approach is that knowledge and understanding of the macroinvertebrate community in tropical Asia is still in its infancy (Dudgeon 1994b, Yule 1995). In particular, the nature of the benthic community in tropical forests is poorly understood (Hildrew and Giller 1994). This is another aspect which interests the author and a baseline study of the community in a pristine upland tropical forest was made to examine its key features.

Study design

This study has the overall aim to test the utility of biological data in summarising and understand stream and river water quality in north east Thailand. It will do this through several case studies which have both a descriptive and analytical component.

At the level of information available, it will remain necessary to use physicochemical data as a general template against which to test the sensitivity of the macroinvertebrate data. Clearly, a series of more independent tests would be desirable as well as experimental testing of key species under highly controlled conditions not readily available in the field.

Chapter 2 uses the important Cheon River as a case study in which to describe the changes in physico-chemical and biological variables at various sampling sites variously impacted by land use change. Sites range from pristine to heavily impacted. Differences in the temporal and spatial distribution of the fauna are highlighted and relationships between changes in the benthic community and corresponding environmental attributes are explored.

Chapter 3 describes the spatial and temporal distribution patterns of the benthic macroinvertebrate fauna of the Pong catchment, a tropical floodplain in north east Thailand. Further, it explores the relative importance of seasonal and human impacts upon this fauna.

The aim of Chapter 4 is to objectively test the utility, in the Thai environment, of some commonly used indices and scores using data collected from quantitative and qualitative methods in the Pong catchment.

Chapter 5 seeks to determine a protocol which combines sampling efficiency with effectiveness in quantifying water quality impacts. Using multivariate analyses it explores the utility of data at several levels of resolution in taxonomy (family, genus, species) and censusing (density, presence/absence). Water quality variables are used as a common point of reference in order to determine a preferred protocol.

Finally, Chapter 6 provides the first description and analysis of the aquatic invertebrate fauna of the pristine upland forested Phukradueng catchment in north east Thailand. Spatial and temporal aspects are explored as well as the role of microhabitat in patterning the distribution of a number of species.

CHAPTER 2

Variation of Water Quality and Benthic Faunal Community: A Case Study of Tropical Headwater Catchment Degradation

Introduction

Most tropical Asian streams and rivers are now under some threat of degradation, chiefly caused by anthropogenic disturbance (Dudgeon 1992, 1994c). The two main sources of human influence on Asian stream and river ecosystems are modification of catchments and flood plains for crop cultivation and river regulation and control.

Land clearing for growing increasingly extensive agro-industrial crops currently affects the headwaters of many streams and rivers in Thailand. Suspended solids diffusing from cleared lands into these streams are a conspicuous problem, particularly during the monsoon season. Substantial loss of vegetation is an on-going problem, as the local villagers seasonally clear vegetation every year.

The Cheon headwater catchment, the subject of this study, was reported by Tangtam and Aimpan (1995) to be losing forested land at the rate of 2.1 percent per year. During summer, the local people regularly burn grasses and large trees for extensive annual planting of tobacco, sugar cane, corn, and many other vegetables. The consequences of this habitat modification for the native flora and fauna are not documented.

Soil erosion is a serious problem in these catchments. FAO (1966) recommended the protection of tropical lands with a slope greater than 35% to prevent surface soil erosion. Although the Cheon catchment is generally less steep than this, it is still facing an increasing problem of extensive surface soil diffusion by overland flow, particularly during the monsoon season. Such excessive runoffs within this catchment are mainly related to the loss of vegetation cover since 70% of the land has been cleared for corn and sugar cane cultivation. Also, the high annual rainfall of the catchment, averaging 1378 mm/year with 103 wet days, further exacerbates the problem.

Tangtam and Aimpan (1995) reported that this catchment, in particular, has suffered severely from top soil loss, as high as 18 tonnes/ha/year, yielding an excessive sediment input to streams and rivers. They also concluded that the key to relief from mass sediment flows was to restore and manage the vegetation that formerly lined the riparian zone.

The Cheon headwaters used to be a very important rainfall catchment which historically supplied permanent freshwater to northeast Thailand. The upper Cheon catchment is now extensively denuded of native vegetation and no longer contributes substantial water to the lower flood plain.

The Thai Government has recently initiated a rehabilitation program for the Cheon. However, the restoration planners argue that much base line information on the Cheon catchment is needed, especially more data on the magnitude of impacts on the flora and fauna of the headwaters. Studies urgently required include the extent of catchment ecosystem degradation, fauna species distribution and water quality profiles (Taksin Soukrasa, director of the Cheon restoration project, personal communication 1997).

Some limited recent information, however, is available and this mainly relates to land use and variation of some water quality variables. These data were obtained on a short visit by investigators from Kasetsart University, Thailand, during March 1995, and their key results are quoted in this study. In their final report, the Kasetsart assessment team concluded that there remains a large number of studies required, generally regarding the aquatic environment (Tangtam and Aimpan 1995).

Specifically, the report highlights two imperatives for research. Firstly, the need for studies which detail water quality changes between seasons within the catchment, and secondly, the documentation of aquatic fauna species and their distribution and abundance over the catchment streams. The latter aim, in particular, seeks to relate the faunal distribution patterns to aquatic ecosystem deterioration within the Cheon catchment.

The aquatic macroinvertebrate fauna, both at community and species levels, is one of several criteria available to assess land-water related environmental impacts (e.g., Hellawell 1978, Wright *et al.* 1984, Abel 1989, Plafkin *et al.* 1989, Friedrich, Chapman and Beim 1992, Lenat and Barbour 1994, Barton 1996, Matagi 1996). For catchment studies, the distribution of the macroinvertebrate fauna can be an effective tool in quantifying either stream degradation or restoration (Richards and Minshall 1992, Richards and Host 1993).

However, most studies of macroinvertebrate communities associated with environmental degradation have been conducted in the temperate zone, and only very few in Asia. According to Chaiyarach (1980) and Dudgeon (1994), aquatic environment studies in tropical Asia are urgently needed to contribute to better water resources management.

Since the Choen catchment is in such a vulnerable condition, and because background information on existing aquatic environment variation is urgently needed, the author initiated the present study which was partly funded by the Thailand Research Fund (TRF). This study is thus a contribution to foundation research which aims to determine the utility of aquatic macroinvertebrate communities as indicators of headwater catchment degradation in Thailand.

Study aims

The major focus of this research is to establish baseline data and to study environmental variation of a tropical catchment headwater, the Cheon catchment. Particular emphases are on examining the catchment water physicochemical quality variation as well as its corresponding aquatic benthic macroinvertebrate community. The analysis of macroinvertebrates, in particular, will focus upon community change and seek to determine whether its variation reflects adverse effects from environmental degradation.

Description of the Cheon catchment

The Cheon catchment is located on the northeastern plateau of Thailand, 570 km northeast of Bangkok and has an area of 727 km^2 between latitudes 16° 30'-16° 54' N, and longitudes 101° 30'-101° 55' E. Its altitude ranges from 280-780 m.s.l. The landscape of the Cheon is mostly hilly valleys and its landform is classified as a slope complex, with slopes ranging from 6-27%. Most of the catchment terrain is now modified for growing seasonal crops, especially mixed horticultural crops, on slopes which are mostly cleared from native forest.

The climate of the catchment features an annual pattern of alternate wet and dry seasons. The dry season extends from November until March, and the wet monsoon season extends from late April to October each year (Table 2.1). On the lower flood plain, however, the beginning of the wet season is typically delayed until late May and continues until October.
The rainfall regime of the catchment differs geographically. The upper flood plain has a seven month rainy period and an average annual rainfall of 1378 mm, while the lower plain has a shorter wet season of six months for an annual total of 1034 mm. The annual average temperature of the upper catchment is slightly less than the lower plain, reaching a maximum in April and May of 29.2 °C, while the coolest month of December averages 20.7 °C. Table 1 summarises the annual climate of the Cheon catchment.

In March, the evapotranspiration rate is at its highest, and humidity at a minimum. The Cheon catchment at this time is a dry, harsh landscape and bush fires, including forest burning by the local inhabitants, occur frequently. March to early April is also the time when the local people are most likely to clear land for planting crops.

The Cheon catchment is underlain by sedimentary rock which mostly consists of sandstone, shale and siltstone substrata. The surface soils belong to the red yellow podsolic great soil group. They have an average depth of 0.50 m and are mixed with sandy and clayey loam. With intensive cropping expanding in the catchment during the past several decades, the soils have become less fertile and thus artificial fertilisers are usually applied.

Table 2.1 Mean monthly climate of the Cheon headwater catchment, Thailand 1982-1994 (after Vanavong 1995)

Month	Rainfall (mm)	Temperature (°C)			Evapo-transpiration (mm)	Humidity (%)
		Max.	Min.	Mean		
January	11.9	29.9	13.8	21.9	2.4	73.1
February	12.4	33.4	13.8	24.9	3.6	70.5
March	56.7	35.8	16.3	19.4	4.6	66.8
April	104.6	37.1	19.4	22.2	4.4	72.9
May	222.8	35.4	22.2	23.0	3.7	77.7
June	139.9	34.6	23.0	23.4	3.4	78.4
July	133.6	34.2	23.4	23.2	3.3	77.5
August	178.5	33.8	23.2	23.2	3.0	78.4
September	273.2	33.5	23.2	22.6	3.1	82.2
October	191.3	31.7	22.6	20.8	2.9	80.3
November	22.8	30.6	20.8	17.4	2.4	79.4
December	29.8	28.4	17.4	13.0	1.9	78.1
Total	**1378.1**	-	-	-	-	-
Mean	-	**33.2**	**238.4**	**19.9**	**3.2**	**76.3**

High levels of coarse and fine suspended solids diffusing from the croplands were observed during pre-surveys conducted for this study. These caused the catchment streams and rivers to appear very turbid, especially during the rainy season.

Although large areas of the catchment have been modified for extensive cropping, there still remains some remnant vegetation within the catchment. Most such patches are riparian trees and shrubs which line the river banks. These remnants are expected to have an important role in helping support aquatic ecosystem functions within the catchment. Also, these riparian strips act as barriers for intercepting excessive surface runoff from the croplands flowing into the catchment streams.

It can be observed that wherever streams of this catchment have broad strips of buffer vegetation, the water appears to be relatively clear and less turbid, particularly during the wet season. These riparian corridors are mostly mixed vegetation communities comprising deciduous and dry evergreen trees. The local people seem inclined to preserve these vegetation strips, especially in the upper catchment reaches. However, in the lower catchment, the people tend to use the riparian zone for growing crops right up to the stream edge.

The only remaining large area of native forest is located in the northwest of the Cheon basin (Fig.2.1). The vegetation community here is mainly dry evergreen forest and covers approximately 15% of the total catchment area. This is where the first sampling station was established, and it is intended to be a reference site for comparison with increasingly impacted sites downstream. The forest community at this site is relatively pristine and protected within the Nam Nao National Park.

Study sites

Six sampling sites (A-F) were necessary to represent the considerable variation in the macroinvertebrate communities and landuse patterns of the Cheon waterways. These sites were located along a gradient of environmental impact from pristine, to moderate and severely disturbed situations, as well as representation of the lower stream reaches.

Reference site A was situated in a protected area of dense forest, located 30 km from Nam Nao District, and was a control for comparison with human disturbed sites downstream (B to F in Fig. 2.1). Site B, about 10 km northeast of site A, was considerably affected by nearby land modified for cornfields and had a minute riparian strip approximately 1-2 m wide. These two sampling sites were in second order streams which were tributaries of the Cheon river.

Both sites C and D were located in the northeast part of the catchment, and were also second order streams. The area around site C was mostly cleared for cornfields and only some buffer vegetation strips were left along the riparian zone. Site D was located in a stream that runs across a Bhuddist monastery area. The vegetation in this site is relatively protected, and has a dense buffer strip covering the streamside.

Site E was located in the southeastern sector of the catchment, and is characteristic of much of the lowland Cheon watercourse. Here the river channel becomes wider and deeper, particularly during the monsoon months. A patch of sparse vegetation was located along the riverbank. The water current sometimes appeared to be slow and sometimes stagnant, particularly during summer. The surrounding land at this site was cleared for extensive sugar cane plantations.

The last sampling site F was located immediately above the lower flood plain of the Pong. This river stretch was similar to site E, but the adjacent lands were used mainly for residential and agricultural purposes. Local communities inhabited the riverbanks at site F where they also grew a large variety of vegetables. Table 2.2 summarises the major sampling site characteristics, and Table 2.3 presents brief detail of the microhabitat characteristics of each sampling site.

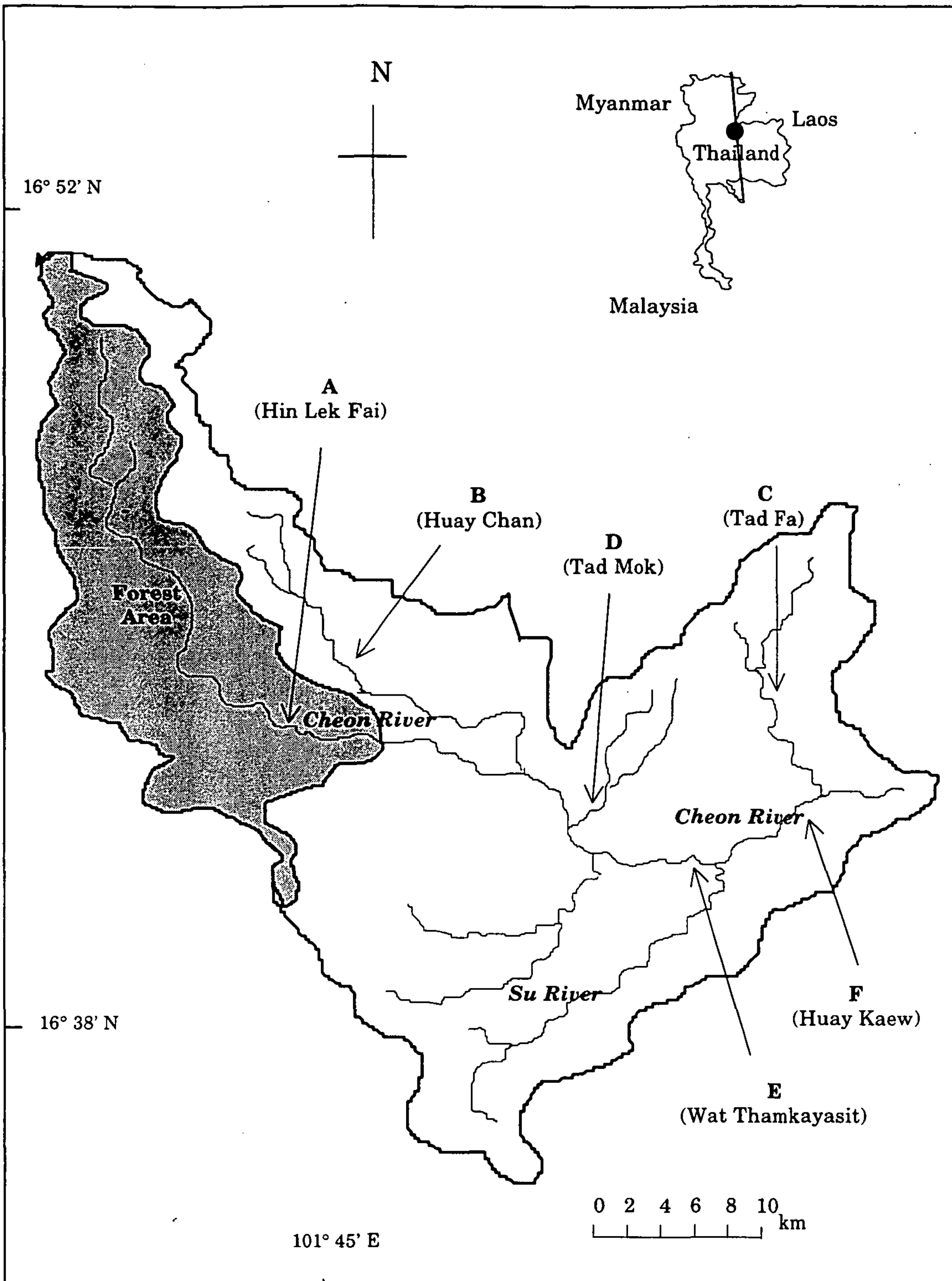


Figure 2.1 Location of sampling sites A-E in the Cheon headwater catchment, with local names in parentheses (redrawn from Tangtam and Aimpan 1995)

Table 2.2 Summary of sampling site locations and their local physical environment

Site	Latitude and longitude	Altitude (m.s.l)	Width (m)	Depth (m)	Surrounding environment
A	16° 46' N 101° 34' E	780	3-4	0.20-0.40	Riparian zone mainly lined with bamboo, and with healthy mixed dense dry evergreen trees
B	16° 47' N 101° 37'E	762	2-4	0.30-0.40	Sparse strip of bamboo and deciduous trees, large corn field adjacent to sampling site
C	16° 44' N 101° 47' E	640	3-5	0.20-0.50	Thick and healthy riparian with mixed shrubs and deciduous trees, the surrounding lands are cleared for corn planting
D	16° 43' N 101° 45' E	700	2-4	0.15-0.20	Very thick and healthy riparian shrubs and other deciduous trees, the stream is dried up during summer
E	16° 37' N 101° 46' E	300	7-15	1.50-3.70	One side of the river bank is totally cleared for sugar cane field, the other side with sparse shrubs and patch of deciduous trees
F	16° 39' N 101° 48' E	280	12-17	1.70-2.90	Only thin zone of riparian shrubs exists, and the banks are cleared for planting vegetables, adjacent to the river bank are local residences

Table 2.3 Microhabitat characteristics of sampling sites, averaged over 100m stretch within which replicate samples were distributed. Replicates were allocated haphazardly to avoid bias.

Site	Microhabitat characteristics
A	Mainly cobble and pebble substrata with attached algae, and with plenty of leaf packs Riparian zone covered with dense standing trees 90% vegetation cover Relatively fast to moderate flowing waters
B	Thick layer of loamy silt/clay lying on bedrock, and with twigs, leaf packs and detritus 1-2 m wide riparian vegetation 50% vegetation cover Moderate to slow water current
C	Boulders and bedrock with attached algae, leaf packs and detritus 10-15 m wide riparian vegetation 60% vegetation cover Moderate to slow flowing water
D	Mainly bedrock and cobbles with attached algae, also a patch of leaf packs 20-30 m wide vegetation buffer strip 70% vegetation cover Moderate flowing water
E	Bedrock overlaid with thick loamy silt/clay 2-3 m wide riparian vegetation strip 30% vegetation cover Moderate to low flowing water
F	Bedrock overlaid with very thick loamy silt/clay 2-3 m wide riparian vegetation strip 15% vegetation cover Moderate to slow flowing waters

(The substratum particle sizes; silt/clay, sand, gravel, pebble, cobble and boulder are classified according to the Wentworth Scales after Cummins 1962).

Materials and methods

Sampling was conducted bimonthly at the six sampling sites, from 8 October 1995 to 20 August 1996. Six replicates (sampling units) were applied to sample benthic animals at each site. The number of replicates used here was determined from a pre-survey examination result using the calculation method of Elliot (1978). A uniform stretch of river waterway at each sampling site approximately 100 m in length was marked, and six replicates were sampled randomly within it. Water physicochemistry data were collected concurrently.

Sampling water physicochemistry used a Van Don bottle at the mid-depth of water column where each of the faunal sampling unit were located. The integrated water sample technique was applied by mixing those six water samples in order to represent the water physicochemistry quality at a site. Preservation and analyses of water samples followed the standard methods described in APHA (1992).

Since there were no gauging stations on this part of the Cheon river, water current and discharge had to be measured in the field. The water flow-rate and discharge were measured applying the conventional hydrological methods as described in WMO (1980). The flow rate was measured at 0.2 and 0.8 of the water depth at the cross-sectional points where the stream width divides into 8 sections, and later average approximate instantaneous water velocity and discharge values were calculated.

All field practices for sampling water physicochemistry followed the guideline methods described in the GEMS/WATER operational guide by UNEP, WHO, UNESCO and WMO (1992). Detailed habitat condition at a site of each visit was also recorded in the inventory form (Appendix 2.1). This was used for recording any environmental changes occurring at a site on each sampling occasion, and also noting results of any water chemistry variables which were measured in the field. This field record sheet was also used throughout the studies in the following Chapters.

The Department of Sanitary Science and Department of Civil Engineering, Khon Kaen University, supported the water physicochemistry analysis equipment and facilities, as well as laboratory personnel. Seventeen water physicochemical variables were examined in the field and laboratory. The variables measured in the field were water velocity, stream depth and width, discharge, water temperature, electrical conductivity (EC), dissolved solids (TDS), dissolved oxygen (DO) and pH. Those water physicochemical variables analysed in the laboratory were alkalinity, turbidity, suspended solids (SS), ortho-phosphate (PO_4), reactive dissolved nitrate-nitrogen (NO_3), biochemical oxygen demand (BOD), chloride (Cl) and sulfate (SO_4).

There were some important points that should be initially noted here regarding the reason why SS and turbidity were chosen for analyses by this study. Sometimes these two variables have been used as surrogates for each other.

In this study the SS level was used to indirectly quantify the magnitude of surface runoffs, and also the sediments input into streams from surrounding lands. The SS was expected to cause microhabitat alteration detrimental for macroinvertebrate colonisation.

Turbidity was selected to measure the visual properties or transparency of water. The turbidity level was expected to condition the degree of light penetration within a water column. Further, the magnitude of turbidity level would determine the extent of photosynthesis (primary production) available for benthic faunal community as allochthonous food sources.

The TDS and EC levels were the other water quality variables that could be used either interchangeably or both. These two variables in fact were used as rough indicators of mineral salt content in waters, when direct measurement of each dissolved ion could not be made. This study attempted to include examination of both variables in order to validate the data, and also to cross check equipment used for measuring the total dissolved ion salts of water bodies in the field. Additionally, this study also attempted to examine the relationship between these two variables. These two variables were interrelated and each could be derived from the other by multiplying a certain fraction as recommended by Chapman and Kimstach (1992).

Benthic fauna was quantitatively sampled following the general methods recommended by Hellawell (1986). Sampling benthic fauna at shallow upstream sites used a Surber sampler (0.30×0.30 m with 500 μm mesh aperture). An Ekman grab (0.15×0.15 m) was used to sample benthic animals in deeper waters at downstream sites. A boat was also used to sample benthic animals and water chemistry at lower reach sites.

Benthic samples (faunal samples plus sediments) recovered in the field were first collected into polyethylene plastic bags and preserved with 90% ethyl alcohol. The benthic samples were then brought to the laboratory where they were washed and sieved using a series of standard sieves in which the last layer retained was at 500 μm mesh screen. It should be noted here that concentrated ethanol was necessary to prevent animal specimens being digested by the bound sediment. The pre-study results found that most specimens recovered were rapidly fragmented and decayed, because in the tropical climate, the high temperature critically increased the rate of sediment decomposition.

The animal samples were then hand-sorted on white trays using forceps. All specimens were identified to the lowest possible taxonomic level using available keys. The specimens were further enumerated and lastly preserved in 70% ethyl alcohol. All of the specimens were labelled and contained in vials.

As an original benthic animal study in this region, the author, as permitted by the Department of Biology, Khon Kaen University, Thailand, established the benthic macroinvertebrate specimen collection. The specimens collected by this study, and all the organisms recovered in the following Chapters, were archived at the Freshwater Biology Laboratory of the Department of Biology, Khon Kaen University (KKU), Thailand. Some specimens were sent to overseas experts, mainly in USA and Austria, for confirmation of their identification and these reference specimens were also retained at KKU.

There are no available keys to the freshwater invertebrate fauna of Thailand. However, the sampled larval specimens appeared to resemble, especially at generic level, taxa represented in North American, European and Chinese keys; thus these three sources were used.

All of larval keys with ecological notes used a combination set of family and generic keys; for Ephemeroptera; Edmunds (1984), Elliott, Humpesch and Macan (1988) and Gui (1994); Plecoptera; Harper and Stewart (1984) and Haper (1994); Trichoptera; Wiggins (1984), Morse and Holzenthal (1984), Wallace, Wallace and Philipson (1990), Wiggins *et al.* (1994), Edington and Hildrew (1995); Hemiptera; Fernando and Cheng (1963), Polhemus (1984), Savage (1989), and Zheng *et al.* (1994); Lepidoptera; Habeck (1994); Coleoptera; White, Brigham and Doyen (1984) and Yang (1994); Odonata; Wesfall (1984) and Zhao (1994); Diptera; Teskey (1984), Gelhaus and Byers (1994); and Mollusca; Upratham *et al.* (1995).

Also, the author established a preliminary voucher system deposited at the Department of Biology, Khon Kaen University, Thailand.

Data analyses

Description

Taxa richness, faunal density, number of organisms, and the percentage of faunal composition were summarised using descriptive statistics. Faunal variation over time and space was examined with univariate analysis. Univariate analysis was also applied to the water quality data set. All descriptive and univariate analyses employed the SPSS package (SPSS 1994). All of the data were tested for normal distribution by a Kolmogorov-Smirnov test and log transformation was used when necessary to improve normality.

The faunal and environmental data sets were further analysed by multivariate analysis in the ecological pattern analysis software package PATN (Belbin 1995). For exploration of the benthic macroinvertebrate data, various related sets of data were input to the multivariate analysis, including presence and absence (i.e. binary) and density of species at all sampling sites. Each data set was classified and ordinated separately.

Classification

The sampling sites based on water physicochemical data were clustered by the hierarchical agglomerative clustering UPGMA (Unweighted Pair Group arithMetic Averaging, Sneath and Sokal 1973).

As water physicochemical variables usually had different scales of measurement, prior to using UPGMA clustering method, they were first standardised by X-X(mean)/X(standard deviation). The water physicochemistry data were clustered based on the Euclidean distance association metric.

The faunal data were classified using TWINSPAN (TWo-way INdicator SPecies ANalysis, Hill 1979). Concordance between TWINSPAN classification site groupings and site ordination patterns was also explored. Discriminant function analysis (DFA) was used to find combinations of predetermined significant environmental variables which best predicts the TWINSPAN site groups (Wright 1995). The significance level for all analyses was set at $P<0.05$, unless otherwise specified.

Ordination

The faunal data sets were ordinated by HMDS (semi-strong Hybrid MultiDimentional Scaling, Belbin 1995), using the Bray-Curtis association metric. Associations between faunal ordination axes and environmental variables were examined using Pearson product-moment correlation.

Correlation between ordination axes and macroinvertebrate taxa were sought using the principal axis correlation method (PCC option in PATN). One hundred Monte Carlo randomisations (MCAO option in PATN) were used to test which taxa significantly correlated to the ordination axes.

Results

Water physicochemistry

Stream discharges within the Cheon catchment varied significantly by site ($F_{5,28}$ = 8.63, P<0.001) (Fig.2.2a). The second order streams of the Cheon river (sampling sites A-D) had low water discharges, whereas the fourth and fifth order stream sites (E and F respectively) were much higher, averaging 0.53 and 8.97 cu.m/sec, respectively. The mean monthly discharge of the catchment reached a maximum in October, the last rainy month, with an average of 8.52 cu.m/sec. The minimum discharge was in a cooler and dry month in February with its lowest level, 1.32 cu.m/sec. The water discharge levels of the catchment sites were also significantly positively correlated to suspended solids (r=0.58, P=0.002), turbidity (r=0.49, P=0.003) and velocity levels (r=0.44, P=0.009).

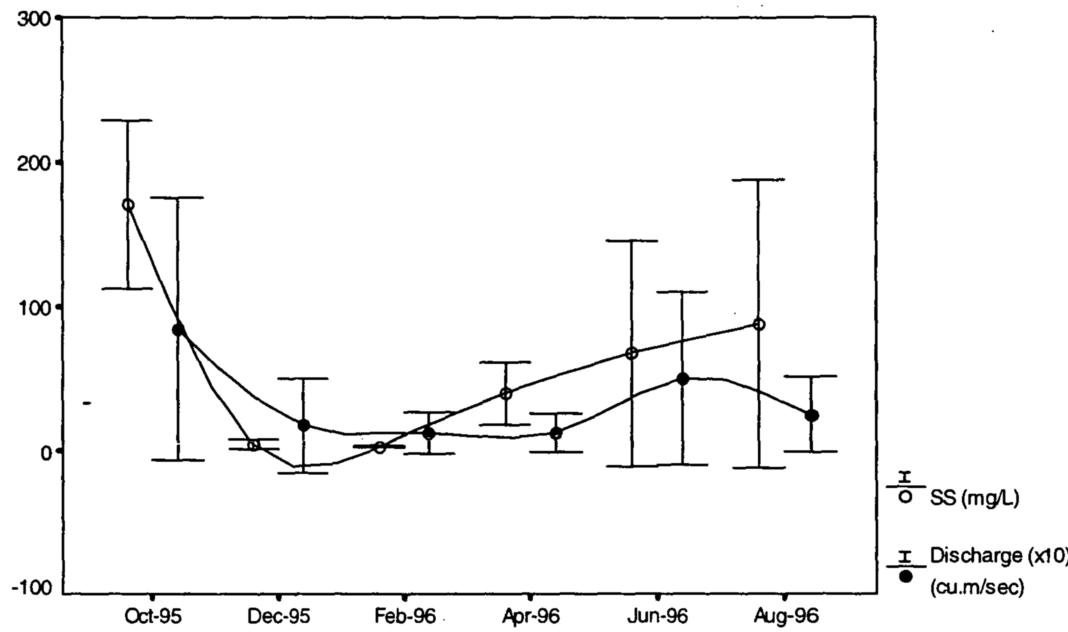
Water velocity, suspended solids and turbidity levels of the catchment streams reflected the temporal and spatial discharge pattern (Fig. 2.2a, 2.2b). The average maximum SS level, in particular, occurred in October, 171.2 mg/L which was in strong contrast to the minimum level in February, 3.0 mg/L. The highest SS level in October was mainly resulting from a high amount of surface discharge flux along the catchment waterways. This also included underground drains, which normally occurred during this time of the year. With higher levels of SS during the rainy season, the water column thus became very turbid, also with many floating plant fragments along the river channels, particularly at lower stream reaches.

Water velocity varied considerably through seasonal regime. During the dry season the waters became almost stagnant in some stream reaches, but in rainy season the water current was turbulent with a maximum velocity of 1.4 m/sec. The mean water velocity of the catchment was 0.4 m/sec. This also characterised a high-low flow regime or wet and dry climatic pattern.

The catchment SS levels measured at all sampling sites also featured a distinct bimonthly variation ($F_{5,28}$=4.3, P<0.01), which mainly followed the high-low flow regime. Further, a very significant difference of SS levels occurred when comparing the average SS levels between dry and wet seasons, which were 4.2 and 96.3 mg/L, respectively ($F_{1,32}$=9.43, P<0.01). Spatial variation of SS levels was also evident when comparing between upstream and downstream sites. The upstream sites (A-D) had an average SS level lower than the downstream sites (E-F), which were 57.3 mg/L and 74.6 mg/L, respectively.

The SS values were positively highly correlated to turbidity (r=0.84, P<0.001). The SS and turbidity levels appeared to highly fluctuate between months within a year. Generally, their levels were very high during rainy months, but lower in dry and cool months.

(a)



(b)

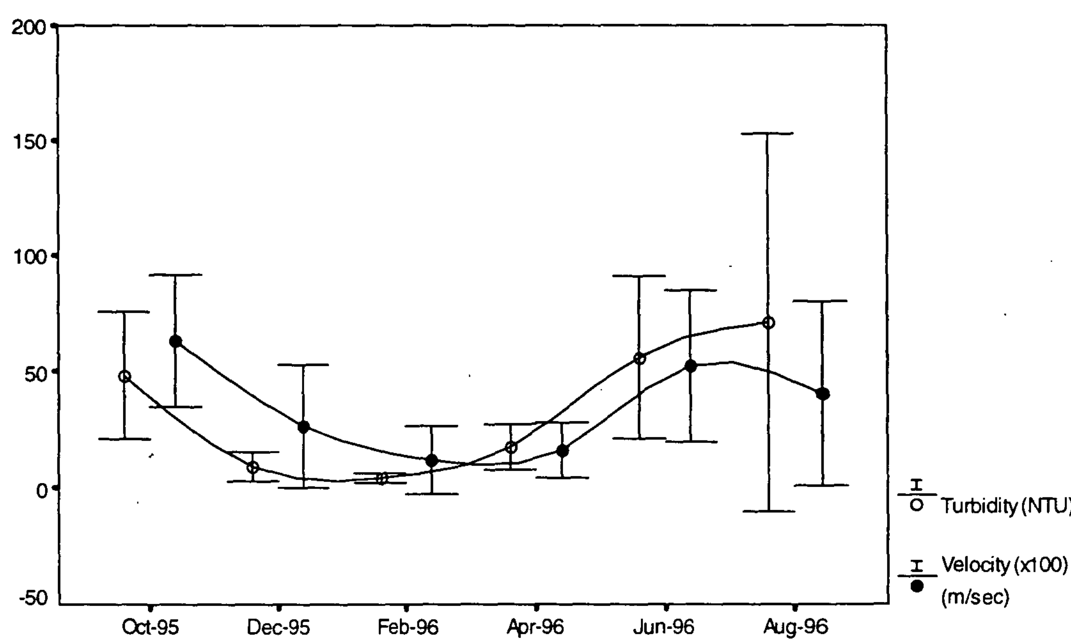


Figure 2.2 Temporal variations of (a) water discharge, suspended solids, and (b) turbidity and velocity levels in the Cheon catchment

Most of the stream waters were severely affected by extensive surface runoffs, particularly during wet season. This was evident through high SS levels which occurred in all sampling streams.

Like SS levels, the turbidity levels of the sampling sites varied distinctively, ranging from 1.8 to 265.0 NTU, with a mean value of 36.0 NTU. The SS and turbidity levels were well related, but they reached their peak in different times (Figs.2.2a, 2.2b). The SS showed the peak value in October, averaging 171.3 mg/L, while the turbidity reached the maximum level in August with a mean of 74.5 NTU.

Air temperature varied markedly between sites. Sites A-D had significantly lower average temperature than sites E and F, which ranged from 24.4-25.5 °C and 27.5-27.6 °C respectively (t_4=5.96, P<0.01) (Fig. 2.3). During the dry season, with relatively cooler climate, the average ambient temperature was lower, 23.8 °C, while in the rainy period the average temperature rose up to 26.8 °C. Average air temperature of all sampling sites reached a maximum in April, 27.6 °C, while dropping to a minimum in December, 22.4 °C.

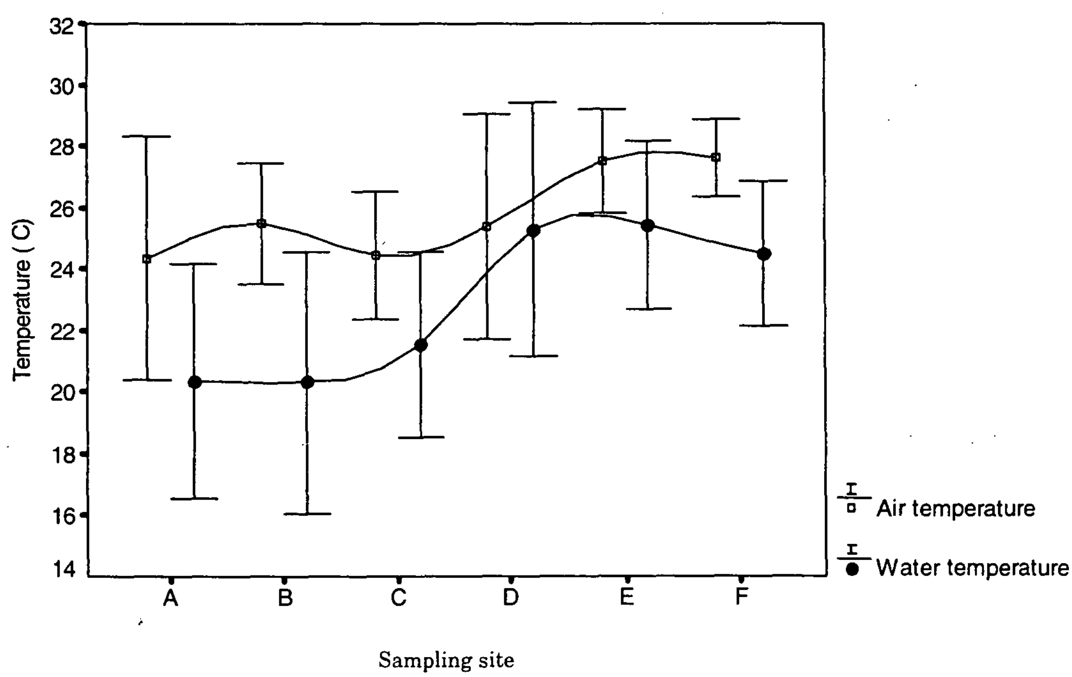


Figure 2.3 Air and water temperature (Mean±SE) variation between sampling sites, the Cheon catchment

The average water temperature significantly differed between sites (Fig.2.3). Sites A and B with relatively high percent forest cover had markedly lower water temperatures than other sites, which averaged 20.3 °C and 24.2 °C, respectively. The water temperature levels also varied between dry and wet seasons ($F_{1,32}$=61.34, P<0.001). The mean water temperature in dry period was 17.7 °C and in wet season was 25.2 °C.

Like the ambient temperature pattern, the water temperature rose to its highest level 25.1 °C in April and then decreased to a minimum 17.2 °C in December. The stream sites located in areas with denser forest cover (A and B) had lower water temperature than the more exposed sites.

In April, there were some sampling sites with water temperatures higher than the ambient, these were sites C and E. It was found that sites C and E had relatively thick buffer vegetation strips, but their surrounding lands had been mostly cleared. Also, this month was the first rainy month when the local climate varied greatly during daytime. These collectively caused the air temperature of the bare lands to vary much during daytime, whereas the water temperature varied minimally.

Dissolved nutrients in waters were measured by this study as orthophosphate (PO_4) and nitrate-nitrogen (NO_3). Both are reactive dissolved nutrient forms for plant growth. The nutrient levels of the catchment waters varied significantly by sites and months. The PO_4 levels ranged from non-detectable levels to a maximum of 1.10 mg/L, with the mean 0.11 mg/L. The NO_3 levels ranged from non-detectable value to the highest level 0.54 mg/L, with the mean 0.15 mg/L.

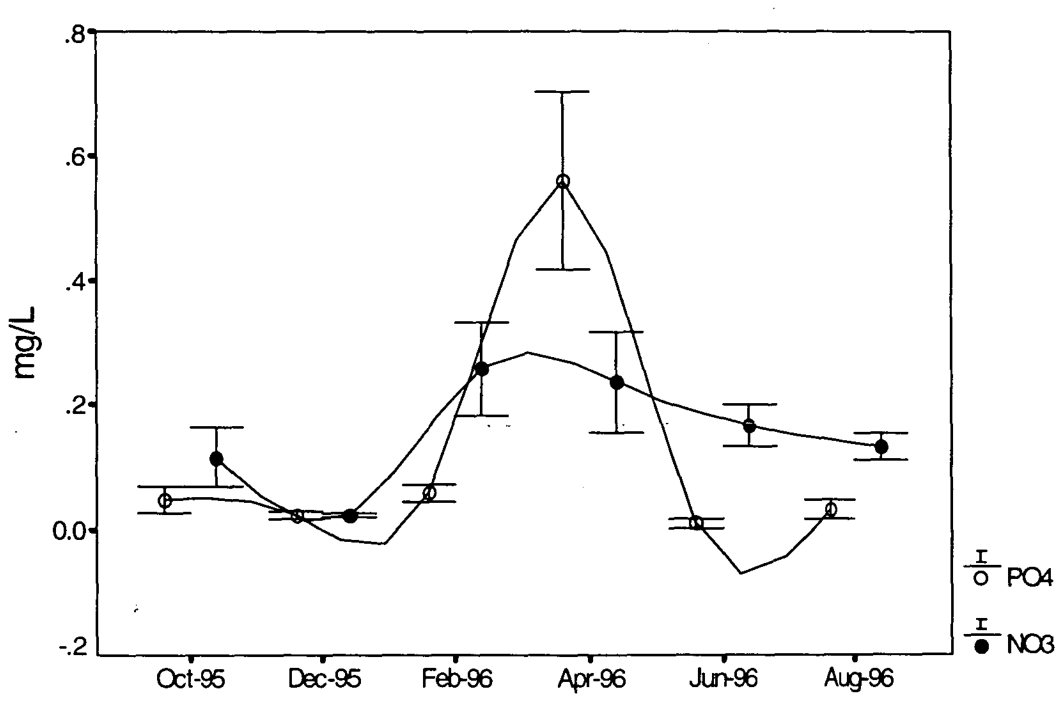


Figure 2.4 Temporal variations of (a) nitrate-nitrogen, and (b) ortho-phosphate levels (Mean±SE) in the Cheon waters

The NO_3 levels varied significantly between months ($F_{5,28}=3.14$, $P<0.05$). The NO_3 in waters were relatively higher in February and April (Fig. 2.4), when they averaged 0.25 and 0.23 mg/L, respectively.

The lowest level of NO_3 measured 0.02 mg/L was in the minimal discharge month of December. It was found that the NO_3 level of the Cheon waters was high during the first rainy month of April. The annual average NO_3 level of the Cheon was 0.15 mg/L.

The waters in sites A and B had low NO_3 levels which were 0.10 and 0.09 mg/L, respectively, while in other sites (C to F) the average levels were higher ranging from 0.16-0.20 mg/L, higher than the average NO_3 content in pristine headwater streams (0.10 μg/L) reported by Maybeck (1982) and Chapman and Kimstach (1992). However, the median NO_3 values of C to F were still lower than the typical values widespread in Asia and Oceania (0.25 mg/L) reported by WHO/UNEP (1987).

The PO_4 levels of the Cheon varied significantly between months ($F_{5,28}$=15.21, $P<0.001$), but not by sites ($F_{5,28}$=0.33, $P>0.05$). The average PO_4 level of all sampling sites was 0.11 mg/L. The PO_4 significantly fluctuated by seasonal regime. In wet season, the average dissolved PO_4 level was higher, 0.14 mg/L while during dry period was 0.04 mg/L. Like NO_3, the PO_4 reached its peak level in April, the first rainy month, averaging 0.56 mg/L (Fig.2.4).

There was a significant variation of TDS levels in all sampling sites which ranged from 41.61 to 360.54 mg/L. The highest average TDS level, 170.84 mg/L, was in the dry and low discharge month of February (Fig.2.5). During the flooding period in June and October, the TDS decreased to an average of 106.96 mg/L. Sites A and B had distinctively lower TDS values than other sampling sites. They had an average of 87.40 mg/L, whereas the mean of other sites was 154.05 mg/L. The annual mean TDS level of the Cheon catchment in all sampling sites was 130.49 mg/L.

The EC level followed the same trend as TDS, its level varied significantly between months ($F_{5,28}$=3.62, $P<0.01$) (Fig.2.5). The EC values of all the sampling sites ranged from 62.4 to 541.8 μS/cm, with a mean of 207.3 μS/cm. The EC levels in December and February months were relatively higher than in other months. Sites A and B both, on average, had lower EC levels than any other sites, which were 129.33 and 248.63 μS/cm, respectively.

The Cheon catchment had high EC levels only in the dry season, averaging 292.12 μS/cm. In the wet season, the EC levels decreased markedly to an average of 166.68 μS/cm.

Seeking correlation between TDS and EC values, I obtained an approximate TDS value in the Cheon waters, by multiplying the EC by 0.66.

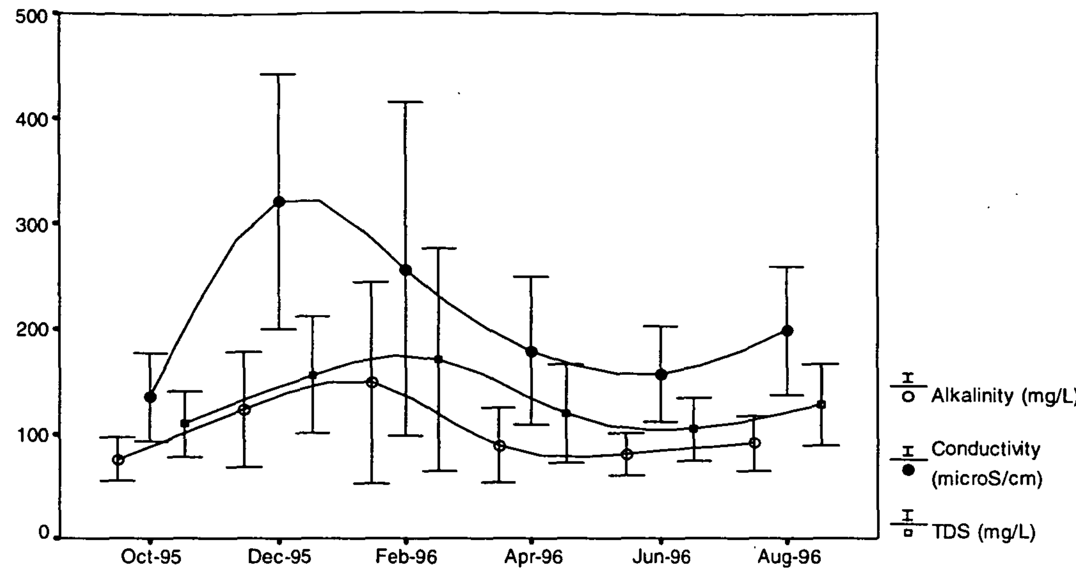


Figure 2.5 Temporal variation of alkalinity, electrical conductivity and total dissolved solids levels (Mean±SE) in the Cheon catchment streams.

The alkalinity values as ($CaCO_3$) in all sampling sites fluctuated similar to TDS and EC levels, and ranged from 36.0 to 318.0 mg/L (Fig.2.5). The average alkalinity level of the Cheon catchment water was 100.6 mg/L.

Alkalinity levels did not vary between months ($F_{5,28}$=1.20, P>0.05), but they were spatially different ($F_{5,28}$=9.16, P<0.01). Sites A, B and F had lower alkalinity levels which were 75.3, 52.0 and 85.0 mg/L, respectively. Sites C, D and E, in contrast, had relatively higher alkalinity values, which were 109.7, 110.0 and 174.7 mg/L, respectively.

The pH levels in the catchment ranged from 6.2 to 8.8, with a mean of 7.8, but there was insignificant variation between sites ($F_{5,28}$=0.79, P>0.05) and months ($F_{5,28}$=2.31, P>0.05).

The SO_4 levels in the Cheon waters ranged from 0.5 to 22.1 mg/L, with a mean level of 10.3 mg/L. The SO_4 level did not significantly differ between sites ($F_{5,28}$=1.31, P>0.05), but it distinctively varied between months ($F_{5,28}$=6.34, P<0.01). The Cheon waters in the wet season had higher SO_4 levels than in dry months, averaging 12.5 and 5.8 mg/L, respectively.

Similarly, the Cl content of the Cheon waters was relatively low and ranged from 3.5 to 15.9 mg/L, with the mean 6.5 mg/L. The Cl level varied significantly between sites ($F_{5,28}$=7.56, P<0.01), but not by months ($F_{5,28}$=1.33, P>0.05). A distinct Cl level occurred in the dry month of December.

The average DO level in the Cheon waters was not high at 6.6 mg/L. Also, DO levels in all sites were well below the national standard 20th percentile value (Fig. 2.6), with the exception of sites A and D. Sites A (reference site) and D (of temporal stream) had DO levels which met the national standard. Relative to this standard, site B had the most severely deficient DO level (Fig.2.6).

The DO levels varied significantly between months ($F_{5,28}=3.51$, $P<0.05$). In the first rainy month, April, the DO decreased markedly to its lowest level, averaging 4.9 mg/L. In the last rainy month October, the DO level increased to an average 5.9 mg/L. Between two cool sampling months, December and February, the average DO levels were comparatively higher at 7.8 and 7.2 mg/L, respectively.

When relating DO with SS levels within the Cheon catchment waters, the DO values were negatively correlated with SS ($r= -0.72$, $P<0.001$) and TDS ($r=-0.77$, $P<0.001$).

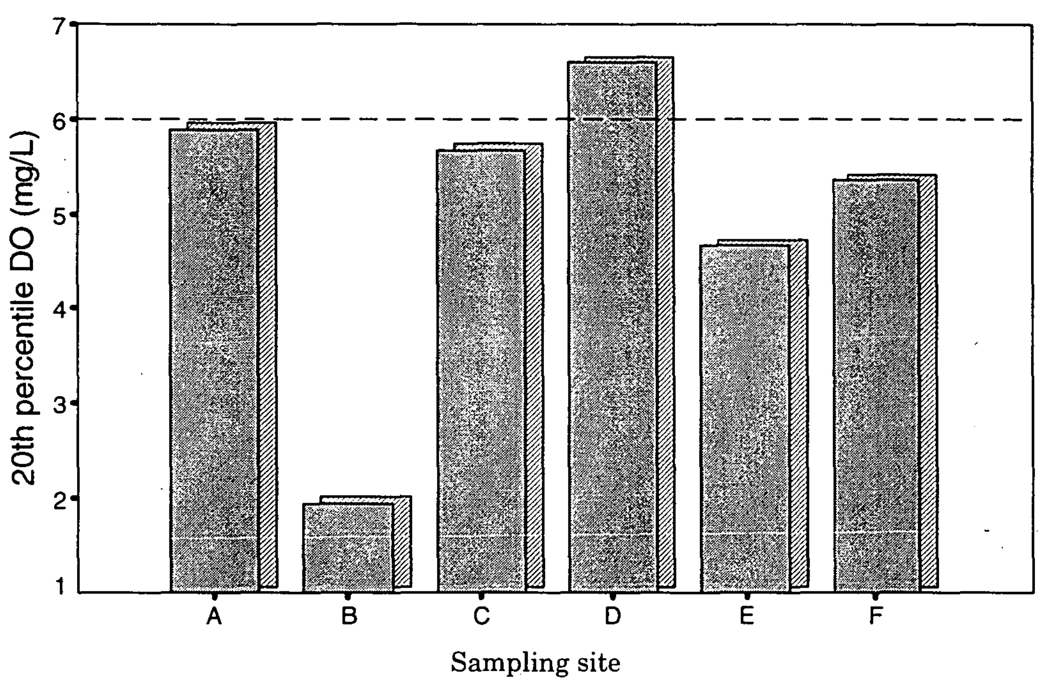


Figure 2.6 20th percentile dissolved oxygen (DO) levels of sampling sites in the Cheon catchment. The dotted line represents the national standard value of 6 mg/L

The BOD level of the Cheon waters varied significantly between seasons ($F_{1,32}=4.35$, $P<0.05$) (Fig.2.7). In the dry season the average BOD level was 1.7 mg/L, while in the rainy period it was 1.2 mg/L. The mean BOD value of the Cheon waters was 1.4 mg/L.

Sites A and D when compared to other upstream sites (B to C) had relatively lower BOD levels (Fig.2.7). Site C, however, had much the highest BOD value. The sites with low BOD values (A and D) also had high DO content.

Given that the natural BOD value generally does not exceed 2.0 mg/L (Chapman and Kimstach 1992), it is noteworthy that there were a number of samples from the Cheon waters which had higher values. Twenty percent of water samples collected during April and February and seventeen percent of water samples in December month had BOD values greater than 2.0 mg/L.

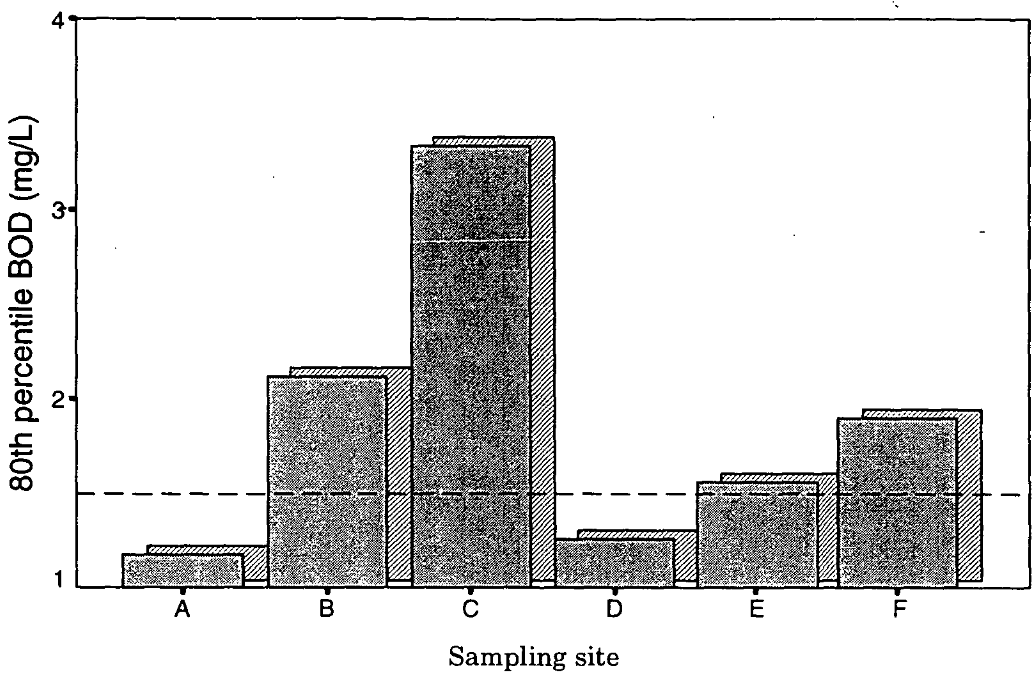


Figure 2.7 80th percentile of biochemical oxygen demand (BOD) values of sampling sites in the Cheon catchment. The dotted line represents the national standard value ≤ 1.5 mg/L

Most sampling sites had BOD values well above the national standard value (Fig.2.7). Sites A and D, in particular, had BOD levels within the standard value. Site C had a distinctive BOD level well over the standard value.

Water physicochemistry and taxa richness

Table 2.4 shows the correlation between major water physicochemistry variables and taxa richness. These results used data only from April, the first wet month, since this is a time of very rapid change in the biota and water parameters. Site D was excluded since there was little water available in the stream at this time. Comparison was made between sites A to C, which were located on the same plain.

Site A (reference site) had low turbidity, SS, NO_3 and BOD while these variables were higher in sites B and C. Site A had higher benthic species richness than the other sites. Caddisfly species richness, in particular, was higher in site A (Table 2.4).

Table 2.4 Water physicochemistry and benthic macroinvertebrate species of selected upstream sites during April, the first monsoon month, in the Cheon catchment

Site	Turbidity	SS	NO_3	BOD	Taxon richness	Mayfly species	Caddisfly species
A	6.5	3.0	0.05	0.73	17	4	7
B	34.7	46.0	0.08	2.37	2	1	0
C	19.8	51.5	0.25	1.86	10	2	1

Site clustering by water physicochemistry data

Figure 2.8a shows the dendrogram of sites clustered by UPGMA based on seasonal water physicochemical data. Most of the sampling sites are clearly separated into two main groups which largely following the seasonal regimes (dry and wet). However, samples taken from both dry and wet seasons in site D are allocated to the same cluster, inferring that water quality in site D did not change much.

Other sites, apart from site D, are well separated in agreement with samples taken by seasonal regime. The most influential physicochemical variables which discriminate the seasonal groups were turbidity, SS, PO_4 (Kruskal-Wallis=8.562, df=2, P=0.0138) and SO_4 (Kruskal-Wallis=7.208, df=2, P=0.0272), all of which had higher mean values in the wet season. Site A, the least disturbed reference site, is well segregated from other sites in both seasons which may reflect a somewhat unique combination of water conditions.

Figure 2.8b shows the cluster dendrogram using only water quality samples taken from perennial streams (sites A, B and C). Again, samples collected from reference site A are generally well separated from other sites. The samples taken from sites B and C, in particular, during December (B2 and C2) and February (B3 and B3), are clearly separated from other samples. SS and velocity are the most significant variables which contribute to the separation of the samples/sites (Kruskal-Wallis=7.075, df=3, P=0.029, and Kruskal-Wallis=8.529, df=3, P=0.036, respectively). Samples taken from sites B and C had relatively high SS levels, and their water currents were comparatively stronger when compared to site A.

Water quality of sampling streams appeared to be more impacted during rainy period. Figure 2.8c shows the samples/sites clustered in wet season.

Sites B and C were relatively well separated from other sites especially in April (B4 and C4), which is the first stormy month, and in June (B5) and August (B6 and C6). The most influential water quality variables contributing to the separation of the samples/sites in rainy season are EC, TDS, SO4 and BOD. The water quality of sites B and C were relatively degraded during the wet season when compared to the reference site A.

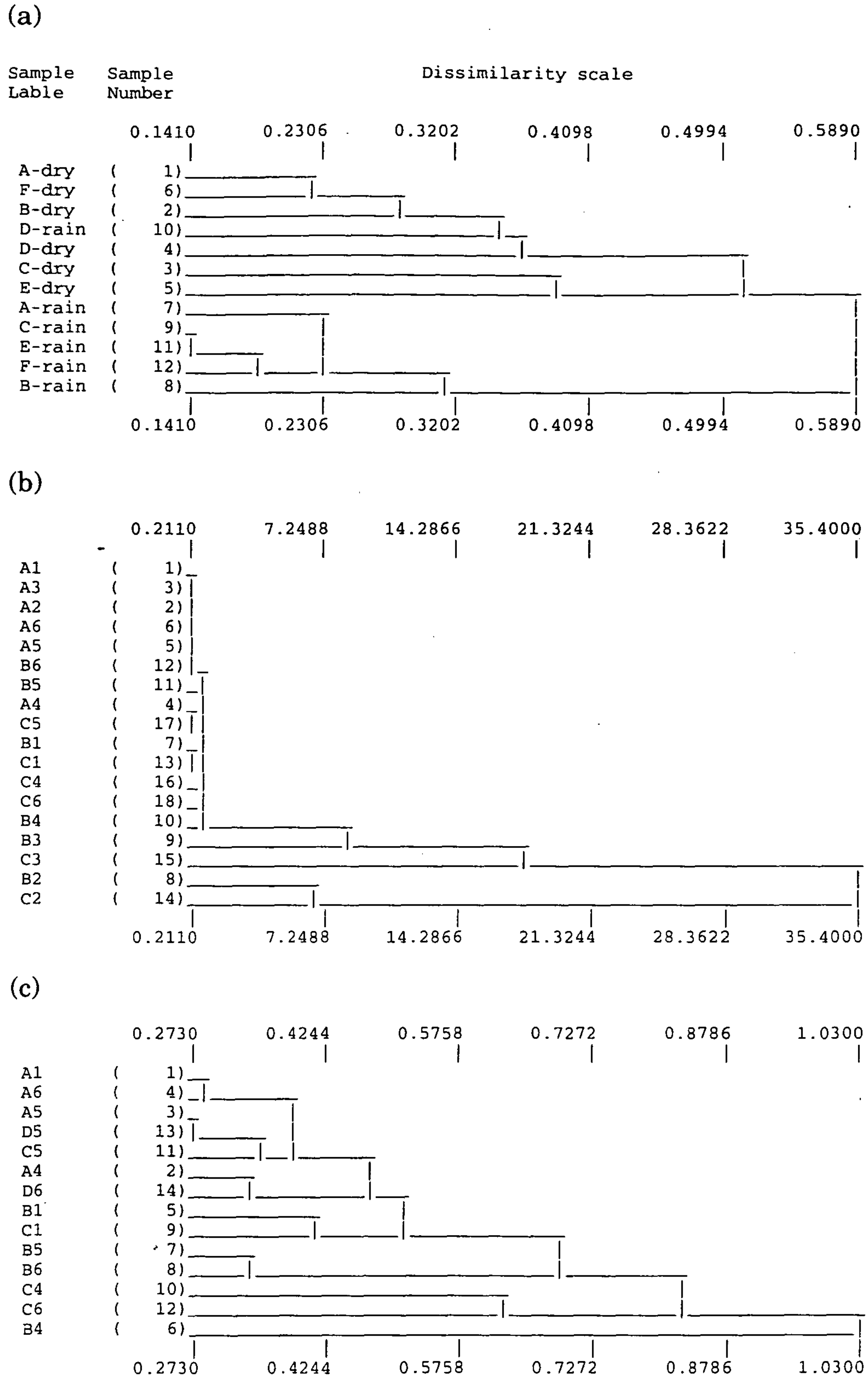


Figure 2.8 Dendrograms from hierarchical agglomerative clustering of sampling sites based on 14 physicochemical variables: (a) all sites seasonally, (b) selected perennial upstream sites, and (c) all upstream sites in rainy season

(Letters stand for sampling sites, numbers represent sampling months, 1=Oct-95, 2=Dec-95, 3=Feb-96, 4=Apr-96, 5=Jun-96 and 6=Aug-96)

Macroinvertebrate fauna: their abundance

During this twelve month study of the Cheon headwater catchment, 4832 benthic macroinvertebrates representing a total of 13 orders, 57 families, 99 species were sampled. Chironomidae and Oligochaeta, however, were counted as a single taxon each since specimens could not be resolved further. Table 2.5 summarises the total benthic macroinvertebrate species and average density per order from all six sampling occasions combined.

Table 2.5 Number of species and average density of benthic individuals of the Cheon headwater catchment

Taxa	Number of species	Density (specimens/m^2)
Insect fauna		
Coleoptera	15	29.10
Diptera	11	211.15
Ephemeroptera	17	118.93
Hemiptera	8	41.41
Lepidoptera	1	11.11
Megaloptera	2	51.85
Odonata	15	59.63
Plecoptera	2	61.11
Trichoptera	23	178.33
Non-insect fauna		
Decapoda	1	23.81
Mesogastropoda	2	5.56
Oligochaeta	1	112.50
Veneroida	1	110.32

The most diverse benthic macroinvertebrates at species level are the caddis flies with a total of 23 species, and these account for 24% of the total number of benthic species discovered. May flies constitute the second largest group, with 17 species. Among insect larval species, the rarest species are lepidopteran and plecopteran taxa with 1 and 2 species each. Dipterans have the highest abundance with a density of 211.15 specimens/m^2. The next most dominant larval taxa are caddis flies and may flies, with average densities of 178.3 and 118.9 specimens/m^2, respectively.

Overall invertebrate density declines downstream. The control site A has the highest benthic animal density with 214.8 specimens/m^2. Sites B to D have 81.7, 128.9 and 17.6 specimens/m^2 respectively. The downstream

stream sites, E and F, have relatively minimal individual density, which are 7.2 and 17.2 specimens/m^2, respectively.

Reference site A, located in an unimpacted forest, has notably the largest density of trichopterans, 319.16 specimen/m^2, while sites B to C have lower caddis density (Table 2.6). Another characteristic feature of site A was an absence of gastropod, bivalve and Oligochaeta. Oligochaeta, in particular, is abundant in site C, 180.6 specimen/m^2, even though this site was located on the same plain as site A.

Table 2.6 Taxon richness and average macroinvertebrate density of all sampling sites, the Cheon catchment

Order	**Species/density** (specimens/m^2)					
	A	**B**	**C**	**D**	**E**	**F**
Insect taxa						
Coleoptera	4/34.72	3/22.22	10/35.90	6/33.33	3/18.89	3/4.17
Diptera	5/34.75	2/25.55	12/314.65	12/2.00	3/7.56	3/19.64
Ephemeroptera	10/115.24	5/66.67	12/113.14	12/19.82	3/9.26	3/11.11
Hemiptera	2/61.11	1/11.11	4/31.11	3/55.55	0/0.00	0/0.00
Lepidoptera	0/0.00	0/0.00	0/0.00	1/11.11	0/0.00	0/0.00
Megaloptera	0/0.00	1/52.78	1/58.33	1/22.22	0/0.00	0/0.00
Odonata	2/77.78	2/111.12	8/76.29	8/24.69	1/5.56	1/2.78
Plecoptera	2/29.63	0/0.00	0/0.00	0/0.00	1/18.34	1/0.00
Trichoptera	15/319.16	3/37.37	12/83.33	10/51.59	1/2.78	1/0.00
Non-insect taxa						
Decapoda	1/44.44	1/16.67	1/14.81	1/44.44	1/0.00	0/0.00
Mesogastropoda	0.00	0.00	0.00	11.11	2.78	2.78
Oligochaeta	0/0.00	1/11.11	1/18.56	1/55.56	1/142.59	1/38.89
Veneroida	0/0.00	0/0.00	1/111.11	1/0.00	1/131.67	1/2.78

Species richness of sites A to F are 41, 19, 57, 48, 16 and 14 species, respectively.

Species richness and density generally declines downstream. Comparing between upstream (A to D) and downstream sites (E and F), the upper sites have benthic 96 species with a mean individual density of 128.9 specimens/m^2, while lower sites have 21 species and 17.2 specimens/m^2.

Site A, the less disturbed site, has the highest macroinvertebrate fauna density, and the maximum number of caddisfly species (Table 2.6). The most common were the trichopterans: *Cheuamatopsyche malaysiensis*, with 1851.8 specimens/m^2, *Synaptopsyche kalkahana*, with 1188.8 specimens/m^2, and the ephemeropteran *Potamanthus* sp. with 966.7 specimens/m^2. The first two trichopteran were the most abundadnt of all the macroinvertebrates at the site.

Site B has a total of 19 benthic species identified. Most abundant species were dipteran Chironomidae spp., the odonatan *Sinogomphus* sp. and the mayfly *Ephemera* sp. with densities of 240.0, 166.7, and 166.7 specimens/m^2, respectively.

In site C, the most dominant species are the mayflies *Choroterpes* sp., *Ephemera* sp. and the caddisfly *Polycentropus* sp. with densities of 283.3, 233.3, and 183.3 specimens/m^2, respectively.

Site D, in the intermittent stream, is dominated by mayflies *Ephemera* sp., *Heptagenia* sp. and Chironomidae spp. with 438.9, 355.6 and 375.0 specimens/m^2, respectively.

The two lowland sites, E and F, are notably different in their fauna from the other sites and are dominated by Diptera, Oligochaeta and bivalves. The individual densities of Oligochaeta and *Corbicula brandina* which dominate Site E are 142.6 and 131.7 specimens/m^2. The dominant species of site F are Chironomidae spp. and Oligochaeta, which have the same individual density of 38.9 specimens/m^2.

Benthic species-site specificity

A number of interesting species were largely confined to a single site, suggesting they are either rare species of limited distribution or else limited by particular water quality parameters only found at certain sites. Four caddis species were virtually restricted to site A: *Cheumatopsyche malaysiensis*, the species with the highest density recorded in this study, *Stenopsyche siamensis, Hydropsyche* sp., *Amphipsyche meridiana*, and *Tinodes* sp. *S. siamensis* is a very rare species in Thailand and 4 specimens found during the sampling in April 1996. This endangered species is otherwise limited to a small pristine stream in Nam Nao National Park (Dr Narumon Sangpradub, Khon Kaen University, Thailand, personal communication).

Hydropsyche sp. was found only in site A in October 1995 and June 1996 as densities of 11.11 and 200.00 specimens/m^2, respectively. This filtering collector species appeared to be washed out by high water velocity at site A, particularly during October. *Amphipsyche meridiana* is one of the tropical caddis species also found in Java, Indonesia (Boon 1984). This species was limited to site A and builds its case on large clean cobbles. It was found only in December and April months when the water in the site was clear and had moderate current speed.

The gallery-building psychomyiid caddis *Tinodes* sp. was a rare species in this catchment and only present at site A. Only 12 specimens were sampled, 8 and 4 specimens being recovered in April and June, respectively. This species colonised and built its galleries on large clean cobbles at site A. Most of the larval stages of *Tinodes* sp. are still unknown in this region. Although uncommon in the Cheon catchment, *Tinodes* sp., was found to inhabit most streams of the nearby Phukradueng National Park, Thailand, the most pristine forest area of the region (Chapter 6).

The polycentropod caddisfly, *Neureclipsis* sp., was another species limited to site A. Only 1 specimen was found in February, and 6 individuals in June. Specimens collected in February were early instar larvae which developed into late instars by June. The late instar larvae are a free-living form, and likely to occur abundantly in the mid monsoon months.

Mayfly taxa also showed interesting distribution patterns within the Cheon catchment. *Potamanthus* sp. was the dominant mayfly at site A, with a density of 666.7 specimens/m^2, but was only present in February when the water quality was very clean with a BOD level of 0.5 mg/L, the lowest ever found in all sampling occasions in all sites. The water body was also highly oxygenated with relatively high DO level, 7.6 mg/L. *Potamanthus* sp. also inhabited site C but at a lower density, 33.3 specimens/m^2. This species colonised the large cobble habitat at the stream margins where it is less disturbed by the main stream discharge.

The environmentally sensitive scraper mayfly *Heptagenia* sp. was more widespread and abundant in sites A, C and D. Site D, the less impacted site, in particular, had the highest density of this species, 755.6 specimens/m^2 in December. Microhabitats of this site were bedrock overlaid by some pebbles and cobbles. Its buffer vegetation strip was thick and well protected. Also, the DO level of this site was relatively high, averaging 7.2 mg/L. The occurrence of *Heptagenia* sp. was related to DO level. The highest DO level, 7.9 mg/L, was in December, when this species had its greatest density.

Heptagenia sp. also frequently occurred in site A, and was found in four of six sampling occasions within a year. However, in site C, this species was recovered on only two visits. There was no *Heptagenia* sp. in site B, E and

F. In the first flooding month April, site A had nine individuals recovered from four of six replicates, but no *Heptagenia* sp. were found in samples from sites B and C.

Stoneflies (Plecoptera) were relatively rare in this catchment. Two genera of Perlidae, *Neoperla* Needham and *Phanoperla* Banks, were both found in sites A and E, spanning the full altitude range in the catchment (780 to 300 m.s.l). These two species were discovered from site E in December, and in site A in October, February and April. *Neoperla* was recently revised by Sivec *et al.* (1988), while the latter genus, a native of far-eastern Asia, is still unrevised.

Collector Mesogastropoda taxa were comparatively abundant in the lower reach sites, E and F, but absent in the upstream sites A to C. The filtering collector bivalve veneroidan *Corbicula brandina*, in particular, was more abundant in sites C and E in June, at densities of 111.1 and 197 2 specimens/m^2, respectively.

Benthic macroinvertebrate community and their species variability

The benthic individual density and species richness varied between months (Fig.2.9). Both benthic species richness and densities peaked in the dry-cool months and then declined gradually from the beginning until the end of the monsoon season in October. Thus, the highest individual density occurred in December, 217.5±24.1 specimens/m^2 (mean±SD), and lowest in October 52.5±47.3 specimens/m^2. The species richness also followed a similar pattern, and was highest in December with 13.2±8.1 species (mean±SD), and lowest in August at 8.7±5.9 species.

The species richness and individual density varied significantly between seasons (t_{12}=-3.33, P=0.006, t_{12}=2.65, P=0.021, respectively). Within season both species richness and individual densities still differed markedly. The means of species richness were 4.1±4.6 (mean±SD) and 6.5±6.9 in dry and wet seasons, respectively, and the means of individual densities (specimens/m^2) were 108.0±118.6 and 36.6±27.6, consecutively.

Both species richness and densities varied significantly between sites ($F_{5,28}$=8.82, P<0.0001 and $F_{5,28}$=4.55, P<0.01, respectively).

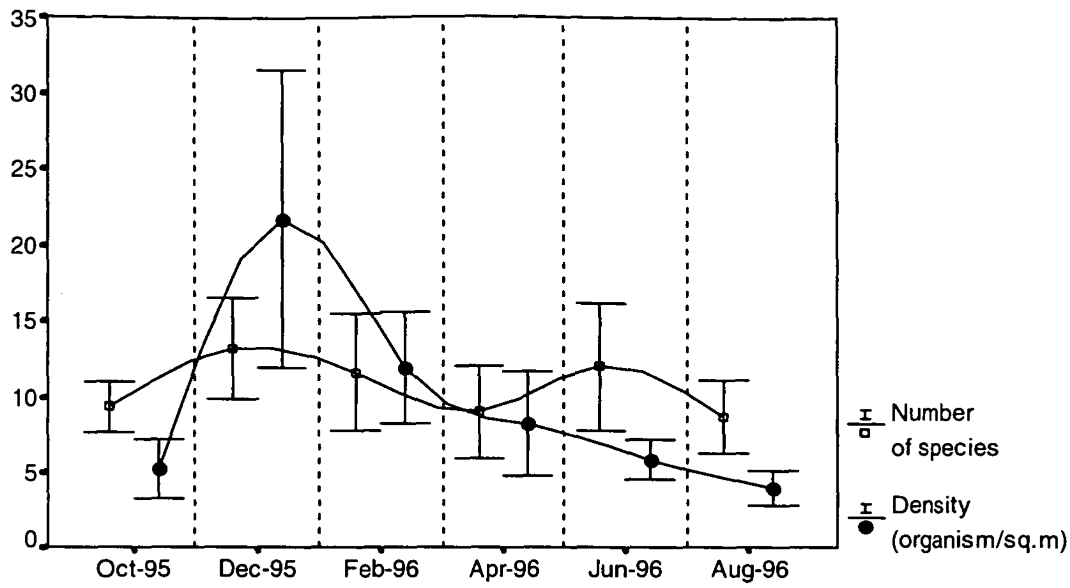


Figure 2.9 Temporal variation of species richness and individual density (x10^{-1}) (mean±SE) of benthic macroinvertebrates in the Cheon catchment

Individual macroinvertebrate density did not vary significantly between months ($F_{5,28}$=1.659, P=0.1772), but significantly by seasonal regime (wet and dry) ($F_{1,32}$=6.231, P=0.018). Animal density was higher in the dry and cool season than in the rainy period, which were on average, 62.6 and 172.7 specimens/m^2, respectively. Species richness did not differ significantly between months ($F_{5,28}$=0.047, P=0.791), or seasonal change ($F_{1,32}$=1.621, P=0.212).

The faunal density within each site varied seasonally (Table 2.7). Site A, in particular, had the greatest faunal individual density variation. This site also had individual density variation greater than inter-site variation (all sites combined). In other words, inter-site variation was less than intra-site variation. The highest variation in site A occurred in dry and cool month with the mean density (specimens/m^2) = 366.1 and variance = 963521.3, while in wet season the mean was 93.8 and variance = 38830.4.

Like site A, the faunal densities in other sites were highly variable. However, intra-site variation in other sites was lower than that of site A (the control site) and inter-site variation. The lower sites (E and F), with less individual densities, had a lower degree of intra-site variation than inter-site variation.

The intra-site faunal density was more variable in the dry season than in the wet period. Site A had the greatest individual density of any site in dry and cool months. Also, this site had the highest species richness of all sites during this time of the year.

Ephemeroptera and Trichoptera constituted the largest proportion of the total macroinvertebrate fauna (Table 2.6). The density of both taxa varied greatly among sites. The less disturbed site (A) had the highest trichopteran density of all the sites located on the same plain ($F_{5,21}$=9.121, P=0.0001) (Fig.2.10).

In December when site A had relatively clean waters, the trichopteran density was highest at 1107.4 specimens/m^2. In contrast, sites B, C and D had lower densities of 27.8, 140.7 and 55.6 specimens/m^2, respectively. Sites B and C had a substratum type similar to site A, but both had a thick overlying silt/clay layer.

Table 2.7 Faunal density (specimens/m^2) of sampling sites, excluding site D (seasonal stream), in the Cheon catchment

Site	Season	Mean	SD
A	Dry	366.05	981.59
	Wet	159.75	366.15
B	Dry	287.50	774.81
	Wet	234.19	331.31
C	Dry	83.73	171.79
	Wet	79.12	151.89
E	Dry	82.54	158.68
	Wet	42.87	55.62
F	Dry	49.69	80.73
	Wet	15.83	30.36
Sites A to F combined	Dry	219.24	617.18
	Wet	65.88	130.32

In August, the last rainy month, there were no trichopteran or ephemeropteran species in site A. The only three taxa found during sampling were dipterans: *Limnophila* sp., Chironomidae spp. and the coleopteran *Cleptelmis* sp. During this month, the water current in site A was relatively strong, 1.4 m/sec, and the site was affected by underground drainage so that the soil became saturated with excess rainfall and thus influenced the stream condition in site A.

In December, mayflies were abundant in sites, A, C and D reflecting the caddis flies distribution pattern. Site A had the highest mayfly density 94.4 specimens/m^2, while sites B and C had 27.8 and 13.2 specimens/m^2, respectively.

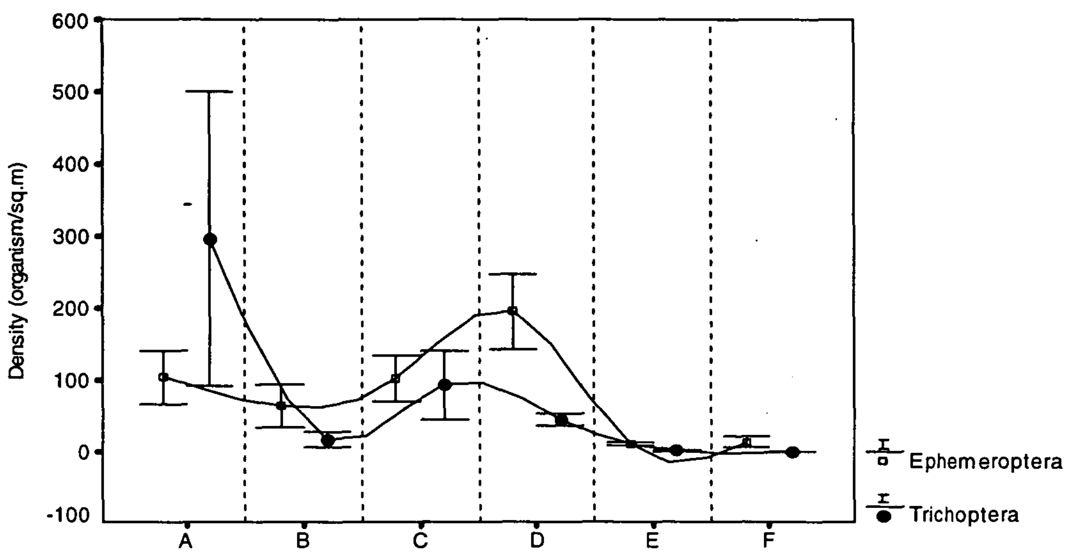


Figure 2.10 Densities of ephemeropteran and trichopteran individuals (mean±SE) in all sampling sites, A to F, in the Cheon catchment

Figure 2.11 shows the TWINSPAN classification result using faunal density data. Eight sample groupings are split at the third level of TWINSPAN division. The samples collected from sites E and F are separated at the first division; however one of the upstream samples, B6, is included in this group. The indicator taxon contributing to the split on the positive side is Oligochaeta, while on the negative side it is the mayfly *Caenis* sp1.

At level 2 on the negative side, all upstream samples are split into four groups, groups 1 to 4. Indicator species at level 2 is the mayfly *Habrophlebiodes* sp., while at level 3 are four indicator taxa, the elmid *Cleptelmis* sp., Oligochaeta, the ceratopogonid *Bezzia* sp. and the megalopteran sialid *Sialis* sp.

At level 2 on the positive side, indicator taxa are the dipteran *Bezzia* sp., bivalve *Corbicula brandina*, Oligochaeta and coleopteran *Stenelmis* sp. At level 3, the indicator taxa are the caddisfly *Phylocentropus* sp. and the beetle *Stenelmis* sp.

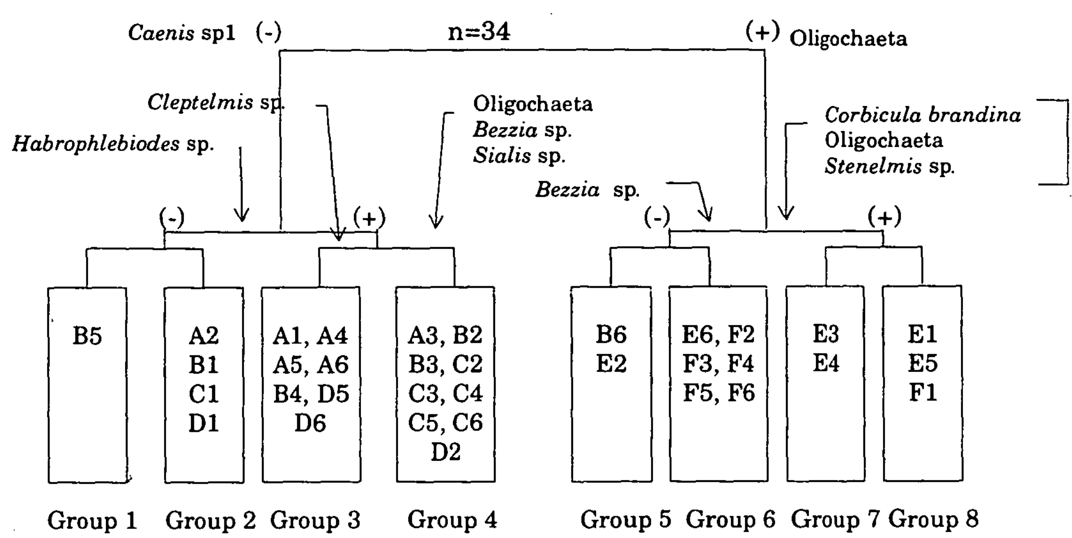


Figure 2.11 Classification of Cheon catchment samples by TWINSPAN. Groupings are retained at the 3rd level of division, including indicator taxa

(Letters represent site codes, numbers stand for sampling months, 1=Oct-95, 2=Dec-95, 3=Feb-96, 4=Apr-96, 5=Jun-96 and 6=Aug-96)

Samples collected from downstream sites are clearly separated into one major group at level 1 (groups 5 to 8), even though these samples were collected in different months of the year.

The indicator taxa produced from TWINSPAN broadly agree with the samples/sites findings (Fig.2.11). The profundal ceratopogonid *Bezzia* sp., Oligochaeta and the bivalve *Corbicula brandina* all prefer to inhabit downstream sites.

The occurrence of the biting midge *Bezzia* sp. was related to water pollution. *Bezzia* was often found in upstream site C. For example, in April, the first monsoon month, site C had the greatest *Bezzia* sp. density 255.6 specimens/m^2 which was the highest density of this species in all sites. At this time, site C also had high average BOD, EC and TDS levels, which were 4.3 mg/L, 313.5 μS/cm and 208.5 mg/L, respectively.

Like *Bezzia* sp., Oligochaeta is an indicator taxon that can identify polluted water samples, particularly the fine separation of samples between groups 3 and 4 (Fig.2.11). The contrast between samples taken from sites C and A is apparent; site C had a high average Oligochaeta density, 466.7 specimens/m^2, while there was no Oligochaeta in site A.

The alderfly *Sialis* sp. is a significant indicator species that discriminates between samples within group 4. This species was found in two sites, B and C. Site C had a maximum abundance of *Sialis* in December of 133.3 specimens/m^2.

Generally, water quality variables differed markedly between TWINSPAN groups, particularly BOD, SS and turbidity ($F_{7,26}=3.439$, $P<0.05$, $F_{7,26}=7.187$, $P<0.001$, $F_{7,26}=3.218$, $P<0.05$, respectively). TWINSPAN groups 3 and 4 had relatively cleaner water quality. Also, both groups had more taxa richness than the others (Table 2.8). The finer difference between sample groups 3 and 4 was indicated by the presence of riffle beetle *Cleptelmis* sp. in group 3 (Fig.2.11). Waters in group 3 had comparatively low BOD, SS and turbidity levels, which were 1.1 mg/L, 19.2 mg/L and 17.1 NTU, respectively.

Of all TWINSPAN groups, sample groups 1 to 4 had cleaner water quality and higher taxa richness than groups 5 to 8. Major focus is then given to the difference between groups 1 to 4. In terms of water quality variables, water discharge and SS were identified by DFA to be the most significant variables. The DFA can predict and separate the TWINSPAN groups 1 to 4 clearly, with 100% success (Fig.2.12). In other words, the difference in taxa richness of sample groups 1 to 4 was very strongly related to discharge and SS (Fig.2.13).

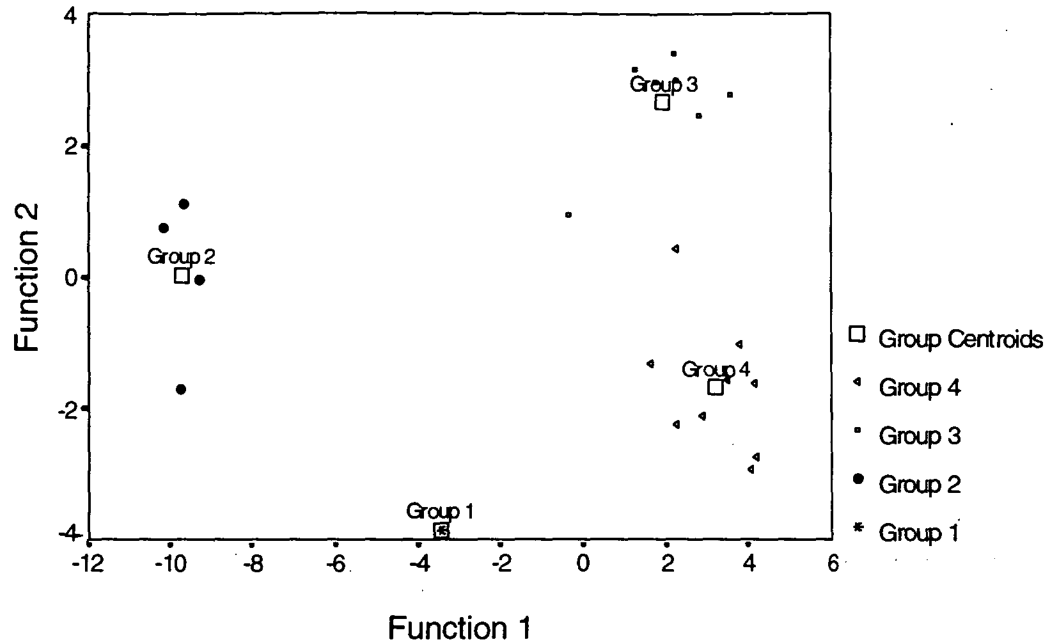


Figure 2.12 A biplot between discriminant functions 1 and 2, the legend groups corresponding to the TWINSPAN groups in Fig.2.11

(Functions 1 and 2 are significant when tested by Wilks' Lambda, P<0.001, P<0.05, respectively)

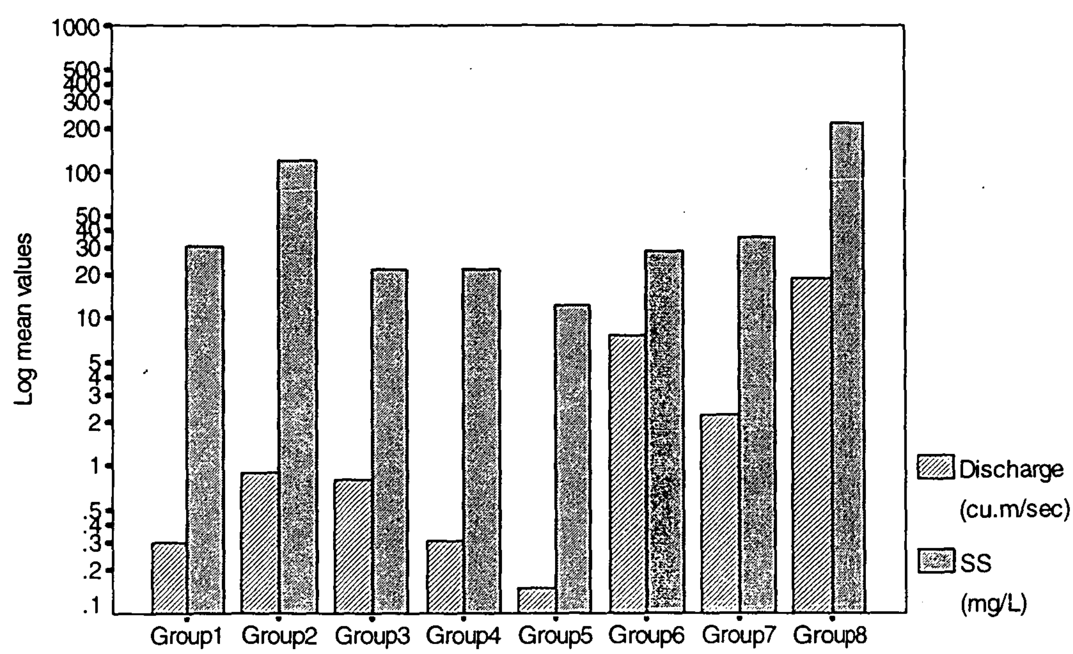


Figure 2.13 Average stream discharge and SS levels of each TWINSPAN group in the Cheon catchment

The water quality variables of sample group 3 indicated less impacted that for group 4, and the difference between these groups was also reflected in the benthic fauna.

TWINSPAN group 3 was mostly comprised of sensitive species less tolerant to environmental stress, including those listed in Hellawell (1986) and Lenat (1993). These are the trichopterans: *Goera* sp., *Hydroptila* sp., *Tinodes* sp., *Molanna* sp., *Anisocentropus* sp., *Chimarra* sp., *Oxyethira* sp., and *Triaenodes* sp.; the coleopterans: *Cleptelmis* sp. and *Dineutus* sp.; the ephemeropterans: *Thraulodes* sp., *Ephemera* sp., *Paraleptophlebia* sp. and *Heptagenia* sp., and the dipteran; *Simulium* sp.

Although TWINSPAN group 4 had the highest taxa richness (Table 2.8), it had less abundant sensitive taxa than group 3. Sensitive taxa of group 4 are the trichopterans: *Chimarra* sp., *Triaenodes* sp., and *Ecnomus* sp.; the ephemeropterans: *Choroterpes* sp., and *Potamanthus* and the coleopteran *Stenelmis* sp.

Table 2.8 Number of taxa per TWINSPAN group

Taxa	**TWINSPAN group**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Insect fauna								
Coleoptera	0	5	5	10	0	3	1	2
Diptera	0	3	6	6	2	3	2	3
Ephemeroptera	0	7	10	10	2	3	2	0
Hemiptera	0	1	3	4	4	0	0	0
Lepidoptera	0	1	0	0	0	0	0	0
Megaloptera	1	1	1	1	0	0	0	0
Odonata	0	6	3	9	0	1	0	0
Plecoptera	0	0	2	0	2	0	0	0
Trichoptera	0	7	18	14	1	0	0	0
Non-insect fauna								
Mesogastropoda	0	1	0	0	0	0	0	1
Oligochaeta	0	0	0	1	1	1	1	1
Veneroida	0	0	0	1	0	1	1	1
Taxon richness	**1**	**33**	**49**	**57**	**9**	**12**	**8**	**8**
Average density (specimens/m²)	**77.7**	**224.1**	**104.3**	**123.8**	**66.3**	**16.3**	**89.1**	**45.5**

Ordination results

The sample ordination results generally resemble those produced by the TWINSPAN. The samples from less impacted sites are ordered at the positive end of ordination axis 1 (Fig.2.14a). This group of samples corresponds with TWINSPAN group 3. The samples from impacted sites (B, E and F) are distinctly separated from the rest in the ordination space.

The ordination result can also identify the sample with more diverse taxa. Sample A3, in particular, located at the highest positive value on axis 1, had the highest taxa richness (21 taxa) suggesting that axis 1 may be a richness vector. .

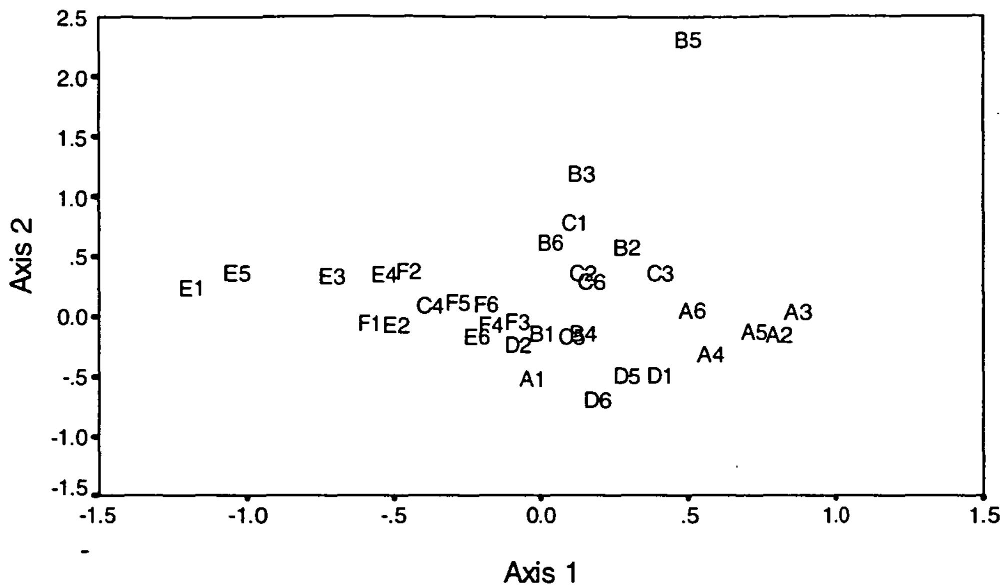
Figure .2.14b shows the taxa vectors that highly correlate with the ordination space, as derived from the Monte Carlo permutation test. There are strong agreements between TWINSPAN indicator taxa (Fig.2.11) and HMDS taxa vectors (Fig.2.14). The two most important indicator taxa produced by TWINSPAN, *Caenis* spl and Oligochaeta, are also clearly identified as influential by the HMDS.

Caenis spl is the indicator species of the first TWINSPAN division (Fig.2.11), and is identified by the HMDS to have a high correlation with the ordination space (r=0.72). The *Caenis* spl vector points towards sites/samples, A, C and D, at the middle of the plot. *Caenis* spl, was a common species that occurred in upstream sites. Oligochaeta also highly correlates with the ordination space (r=0.81), and its vector points to downstream samples/sites.

The elmid beetle *Cleptelmis* sp. vector increases in the direction of samples of sites A and D, where this species was abundant. It was evident that *Cleptelmis* sp. was abundant only in clear and clean waters, as in TWINSPAN group 3. Thus, the *Cleptelmis* sp. vector identified by HMDS is also confirmed by the indicator species produced by TWINSPAN.

Other species which highly correlate with the ordination space are the mayfly *Ephemera* sp. and the alderfly *Sialis* sp. *Ephemera* was abundant in sites A and D, while *Sialis* sp. was often found in site B. All these species vectors point to their corresponding samples/sites in the ordination space. *Sialis* sp. is also the indicator species which TWINSPAN used to split the sample groups 3 and 4. *Ephemera* sp., on the other hand, is not identified as influential by the TWINSPAN.

(a)



(b)

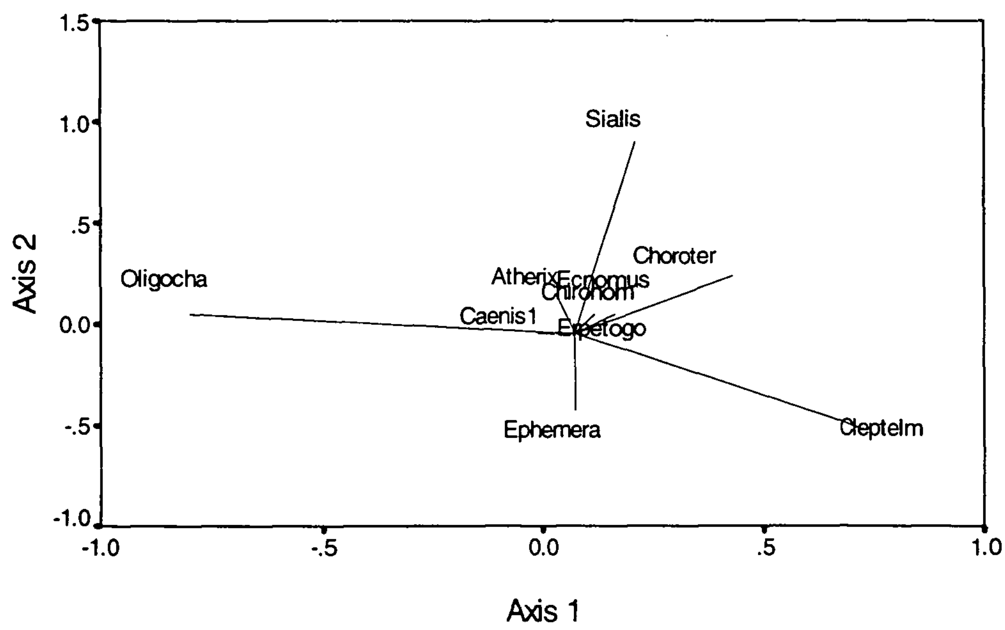


Figure 2.14 Biplots between axes 1 and 2 of (a) samples ordination by HMDS (stress 0.1623), and (b) significant species vectors which strongly correlate to ordination space

Abbreviations; Fig. 2.9a, letters represent site codes, numbers stand for sampling months, 1=Oct-95, 2=Dec-95, 3=Feb-96, 4=Apr-96, 5=Jun-96 and 6=Aug-96;

Fig. 2.9b, a group of letters represent Atherix=*Atherix* sp., Caenis1=*Caenis* sp1, Chironom=Chironomidae, Choroter=*Choroterpes* sp., Cleptelm=*Cleptelmis* sp., Ecnomus=*Ecnomus* sp., Erpetogom=*Erpertogomphus* sp., Ephemera=*Ephemera* sp., Oilgocha=Oligochaeta and Sialis=*Sialis* sp.

There are some significant relationships between the ordination axes and certain environmental parameters. Table 2.9 summarises the significant correlations (Pearson product-moment, 2-tailed test) identified between the ordination axes and environmental attributes.

Table 2.9 Significant correlations between ordination axes and environmental variables in the Cheon catchment

*(*P<0.05, **P<0.01, ***P<0.001)*

Environmental variables	Product-moment coefficient (*r*)	
	Axis 1	**Axis 2**
Air temperature (°C)	-0.35*	-0.05
Altitude (log) (m.s.l)	0.78***	0.02
Buffer strip width (m)	-0.67***	0.45**
Depth (m)	-0.71***	-0.02
Discharge (log) (cu.m/sec)	-0.68***	-0.00
Land use category	-0.71***	0.18
SS (log) (mg/L)	-0.69***	0.07
TDS (log) (mg/L)	-0.29	-0.37*
Stream width (log) (m)	-0.65***	0.05
Turbidity (NTU)	-0.40**	0.32
Water temperature (°C)	-0.44**	-0.23

Altitude is the first environmental attribute that highly correlates with ordination axis 1; the landscape profile had greatest influence on the samples positioning in the ordination space along axis 1 (Table 2.9). Generally, most samples/sites arranging along axis 1 follow their elevation gradient (Fig.2.1, Table 2.2). Sites A to D, however, located approximately on the same altitude, are still separated from each other in the ordination space.

Stream morphology is significantly related to axis 1 (Table 2.9). The difference in channel morphology is clear between upstream and downstream sites (sites A+B+C+D vs. E+F). The stream dimensions among upstream sites (A to D) are almost the same (Table 2.3). Thus, there is no correlation between axis 1 and stream dimension among these sites. Channel dimension only becomes a major factor when comparing all sites in the whole catchment.

Buffer strips and land use category also correlate with ordination axis 1. The width of riparian vegetation significantly correlates with the sample arrangement in the ordination space. The sites with dense forest and thick buffer strip (A and D) are situated on opposite direction to the bare sites along axis 1 (Fig.2.14a).

Water physicochemistry: water discharge, turbidity, SS, TDS, turbidity and water temperature are all significantly correlated to axis 1.

Table 2.9 indicates that among water physicochemistry variables, the physicals, SS and turbidity, have stronger correlation with the ordination axes than the chemicals. Only the TDS, a rough measurement of dissolved ionic pollutants, is slightly correlated to axis 2.

Presence and absence (binary) data

As an alternative to density data, presence and absence (P/A) data was used. Generally, data types produced similar results (Figs.2.11, 2.15). However, the P/A data classified by the TWINSPAN retained at level 3, slightly deviated from the density result. On the positive end, additional samples collected from sites A (A6) and C (C4) are included in this group.

However, there is strong agreement between density and P/A results in terms of indicator species. The most important indicator species, Oligochaeta, is the common taxon used to split the samples at the first level in-both density and P/A TWINSPAN classification (Figs.2.11 and 2.15).

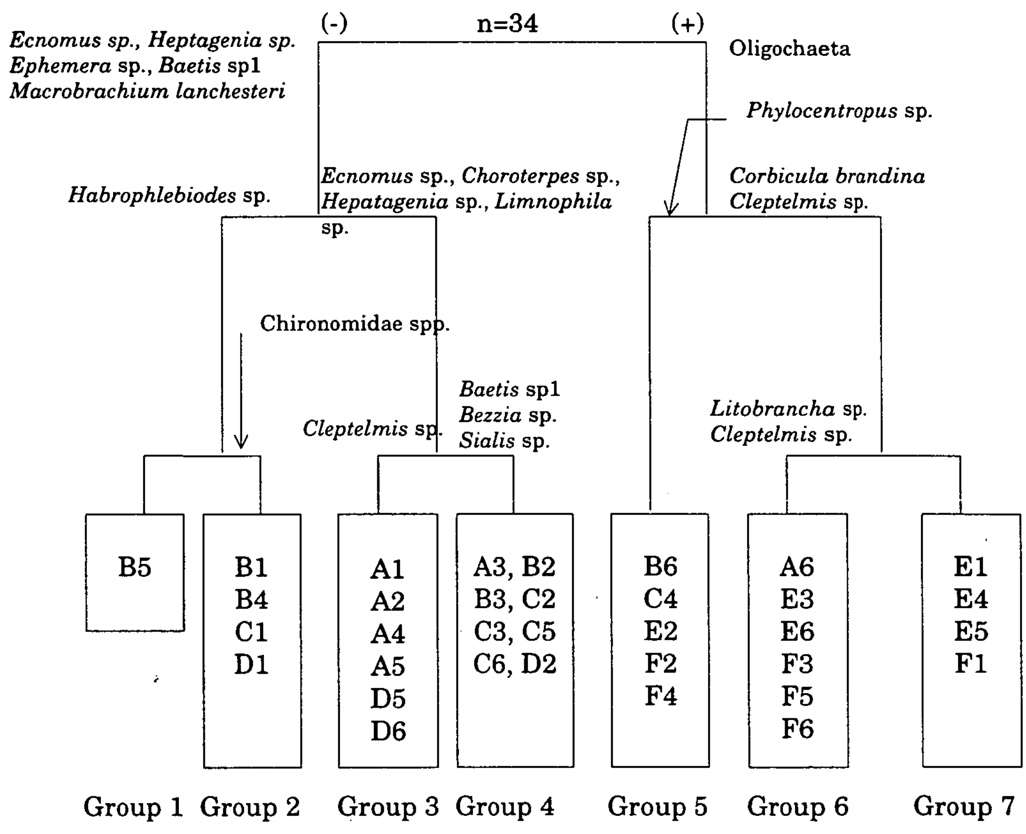


Figure 2.15 Samples classification by TWINSPAN using presence and absence data

(all letters and numbers are the same as illustrated in Fig.2.11, and also used throughout)

Both P/A and density TWINSPAN classification results produce common indicator species: *Habrophlebiodes* sp., *Cleptelmis* sp., *Bezzia* sp. and *Sialis* sp. The last three species are the key species which both P/A and density classifications used to finely discriminate between diverse species samples (groups 3, 4 in Figs.2.11, 2,.15). Thus, the results produced by TWINSPAN using P/A and density data types are largely similar in terms of samples groupings and indicator species.

The P/A TWINSPAN also shows the seasonal sensitivity of sample classification. Sample A6, for example, taken from control site A during a heavy rain in August, is included in the impact groups (groups 5 to 7, Fig.2.15). In August, the water current and SS levels were very high in site A (1.4 cu.m/sec and 329.0 mg/L respectively). Only three benthic species were found, Chironomidae spp., *Limnophila* sp. and *Cleptelmis* sp., and all have claws adapted for anchorage. The control site A was severely disturbed by natural effect only in August.

There are two P/A TWINSPAN groups which have more abundant species; groups 3 and 4 (Fig.2.15). Samples in TWINSPAN group 3 have more abundant sensitive taxa, Ephemeroptera and Trichoptera species, than group 4 (Table 2.10). Group 3 also had better water quality than group 4.

Table 2.10 Taxa richness per TWINSPAN group

Taxa	**TWINSPAN group**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Insect fauna							
Coleoptera	0	6	5	9	2	3	2
Diptera	0	2	6	6	3	3	3
Ephemeroptera	0	6	12	10	4	3	1
Hemiptera	0	1	3	4	0	0	0
Lepidoptera	0	1	0	0	0	0	0
Megaloptera	1	1	1	1	1	0	0
Odonata	0	5	4	8	2	1	1
Plecoptera	0	0	2	0	2	0	0
Trichoptera	0	2	19	14	2	0	0
Non-insect fauna							
Decapoda	0	1	1	1	0	0	0
Mesogastropoda	0	1	0	0	0	0	0
Oligochaeta	0	0	0	1	1	1	1
Veneroida	0	0	0	1	0	1	1
Taxon richness	**1**	**25**	**53**	**55**	**17**	**12**	**8**

Even samples in group 4 have more taxa richness than group 3, but all samples in group 4 have lower sensitive taxa abundance. In addition, the pollution indicator taxon, Oligochaeta, was absent in samples from group 3 (Table 2.10).

The DFA method was employed to study relationships between TWINSPAN groups and water physicochemical variables. The analysis focused only on the correlation between the most abundant fauna samples in TWINSPAN groups 1 to 4 and water physicochemical variables.

The MDA revealed that only discriminant function 1 was significant when tested against Wilks' Lambda ($P<0.002$, 97.15% variance explained). The discriminant function 1 is significantly correlated with alkalinity (log) ($r=0.54$, $P=0.016$), EC (log) ($r=0.58$, $P=0.01$), SS (log) ($r=-0.72$, $P=0.001$) and water temperature ($r=-0.52$, $P=0.023$). SS was the most influential factor that contributed to the separation between TWINSPAN groups 1 to 4. In other words, the existence of benthic taxa in each TWINSPAN group is highly related to SS levels. The average SS levels of TWINSPAN groups 1 to 4 are 31.5, 130.8, 12.3 and 22.5 mg/L, respectively. It clearly indicates here that the more diverse sensitive species occurred in samples/sites in TWINSPAN group 3 may be attributed to less SS (surface runoffs) impact.

Ordination of presence and absence (binary) data

The HMDS ordination analysis was used to confirm the results of the P/A TWINSPAN classification. The result shows agreement between the two methods. The HMDS ordination successfully separated the samples from less impact samples/sites from those of more impacted samples/sites (Fig. 2.16a). The samples from impacted sites are mostly appending close to each other (E's and F's). The samples/sites with more diverse sensitive taxa appear as outliers. However, the arrangement of sample/sites in the P/A ordination biplot is rather vague when compared to the outcome using the density data (Fig.2.14a, 2.16a).

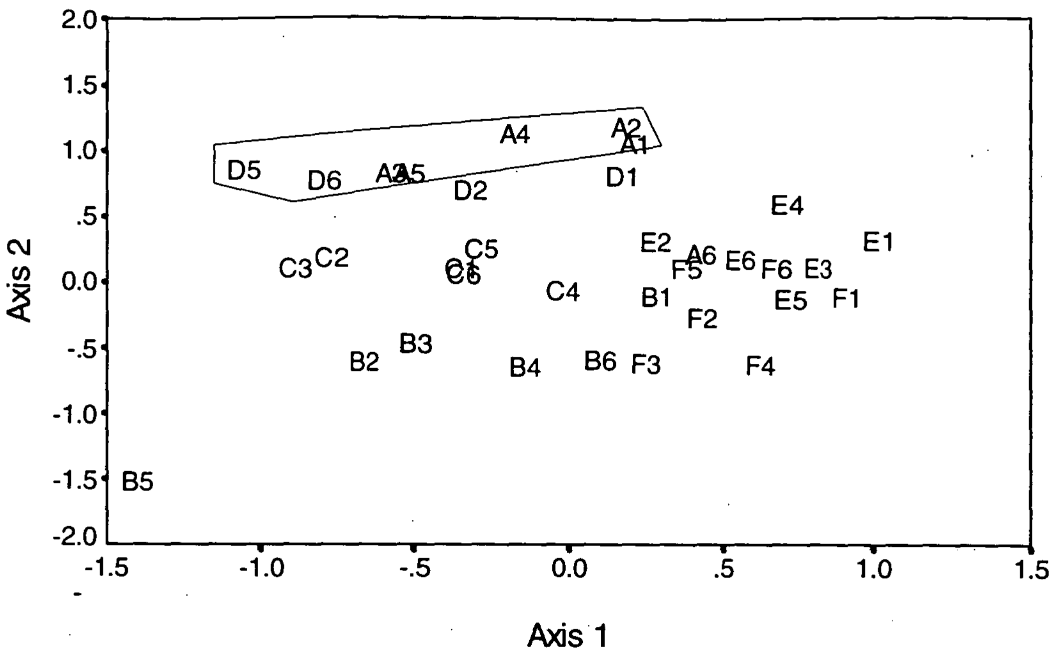
Figure 2.16b illustrates significant taxa vectors which correlate with the ordination space. Most of the taxa vectors point to the samples taken from less impacted sites in the ordination space. Those sites are colonised by mainly sensitive trichopteran taxa. Common taxa that indicate pollution condition point towards impacted sites, for example, Oligochaeta, *Corbicula brandina*, *Bezzia* sp. and *Sialis* sp. These taxa also conform with the indicator taxa produced by TWINSPAN (Fig. 2.15).

Ordination axes are significantly correlated with certain environmental attributes (Pearson product-moment correlation, 2-tailed test). Axis 1 markedly relates to depth ($r=0.66$, $P=0.001$), altitude (log) ($r=-0.72$, $P=0.001$), discharge (log) ($r=0.68$, $P=0.001$), SS (log) ($r=0.36$, $P=0.03$), width (log) ($r=0.62$, $P=0.001$) and water temperature ($r=0.38$, $P=0.02$).

Axis 2 significantly correlates with buffer strip width (r=-0.76, P=0.001), Cl (r=0.39, P=0.02), land use category (r=-0.42, P=0.02), alkalinity (log) (r=0.38, P=0.02), EC (log) (r=0.35, P=0.04), TDS (log) (r=-0.49, P=0.003).

According to the relationship between ordination axes and environmental variables, the buffer strip becomes the most significant factor which conditions the existence of taxa in samples/sites. Other significant environmental variables which relate to the ordination axes when using the presence and absence data are mostly those identified in density data (Table 2.9). However, the correlation coefficients (r) between the ordination axes and some environmental variables when using P/A data are comparatively lower than achieving when using the density data.

(a)



(b)

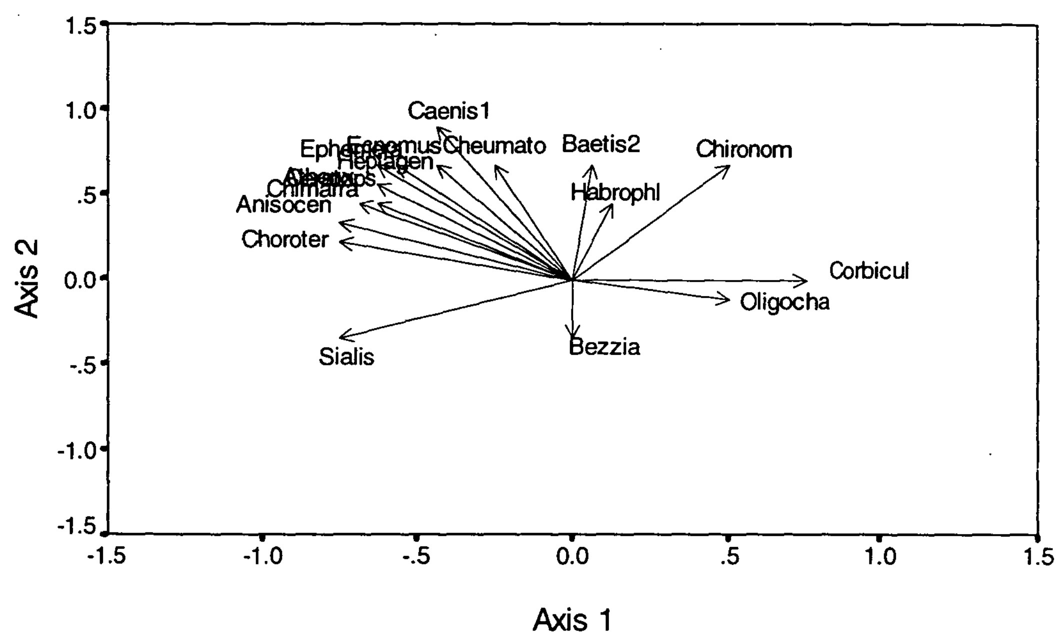


Figure 2.16 Biplots of (a) samples ordination based on presence and absence data (stress = 0.1918), polygon drawn represents the TWINSPAN sample group 3, and (b) significant taxa correlated to ordination space

Abbreviations: Bezzia=*Bezzia* sp., Oligocha=Oligochaeta, Corbicul=*Corbicula brandina*, Chironom=Chironomidae spp., Habrophl=*Habrophlebiodes* sp., Baetis2=*Baetis* sp2, Cheumto=*Cheumatopsyche* sp., Caenis1=*Caenis* sp1, Ecnomus=*Ecnomus* sp., Epheme=*Ephemera* sp., Heptagen=*Heptagenia* sp., Atheri=*Atherix* sp., Chimarra=*Chimarra* sp., Anisocen=*Anisocentropus* sp., Choroter=*Choroterpes* sp. ans Sialis=*Sialis* sp.

Discussion and conclusion

Environmental impact: water quality variation

The variation of water quality in the Cheon headwater catchment generally followed the monsoonal cycle. Like many tropical Asian streams during the rainy season, there were large amounts of sediment diffused from the adjacent land surface into streams (Dudgeon 1995). The high-low flow regime dramatically altered the stream conditions and benthic faunal habitats, reflected in quite a marked contrast of water quality between wet and dry seasons. In reference site A, located in the protected forest area, the water quality did not significantly vary, whereas the sites in bare lands critically suffered from land runoffs.

The impact of land use was clear when comparing between sites A to D which were all located at the same altitude and belong to the same stream-order. The water quality in the forest land site was less impacted than at exposed sites. SS was the most significant water impurity in this catchment. The sites with thick vegetation strips had relatively lower SS levels than the sites with minute riparian zone.

The ambient and water temperatures were also influenced by the magnitude of the surrounding forest. The air and water temperatures at well vegetated riparian sites were lower than at the bare sites.

Surges in the nutrient levels of the Cheon waters became obvious during the first rainy month. In April, NO_3 and PO_4 in streams reached high peak levels. This condition suggested that seasonal rainfall became a major cause of diffused nutrient bound sediment from agricultural lands entering the stream. The study found that fertilisers were widely used during the cultivating season between August and October. In April, fertiliser was then flushed into waterways, resulting in temporarily high nutrient levels in the Cheon waters, however these levels were lower in other months. Thus the dissolved nutrient problem in the Cheon waters was prominent only at the beginning of the wet season.

The most serious dissolved nutrient problem of the Cheon was due to PO_4, which fluctuated between seasons. It was very high in the wet season (0.14 mg/L), and minimal in the dry season (0.04 mg/L). The NO_3, however, did not vary by seasonal regime, its levels were 0.16 mg/L and 0.13 mg/L in wet and dry seasons. In this instance, the results suggested that the NO_3 could be transformed into other forms under the nitrogen cycle.

The Cheon waters had relatively lower average TDS level (151.4 mg/L) than the lower catchment waters of northeast Thailand (573.4 mg/L) reported by KKU (1995).

The Cheon also had lower average EC levels. Thus, the Cheon waters had mild to moderate impacts from dissolved salts, than other sites located in the same altitude. The mean EC level was within the range of average values of the less and severe's impacted catchment. For example, in the Phukradueng catchment, which is about 50 km from the Cheon, the average EC was 8.8 μS/cm, and that of the Pong catchment 120 km from the Cheon, was 874.3 μS/cm.

The Cheon had different alkalinity values between streams. This was due to those streams being located on different carbonate and bicarbonate rock-salt substrata. Despite the high alkalinity and pH levels of the Cheon, it may be classified as a natural water. The Cheon waters had moderate capacity to neutralise acid when compared with the low value of lesser than 24 mg/L (as $CaCO_3$) as reported by Chapman and Kimstach (1995). The alkalinity source of the Cheon was mainly bicarbonate ion. It can be concluded that the Cheon waters showed a normal range of acid-base balance that conformed to natural water values. Although some sites have relatively higher alkalinity levels, but those values still fall within acceptable range of natural waters.

Unlike most streams of northeast Thailand which are severely affected by rock salt weathering, the Cheon waters had less impact from sedimentary salt intrusion. Both chloride (Cl) and sulfate (SO_4) salts measured in the Cheon waters were still at low levels, and did not indicate much impact.

Another important group of water quality variables measured by this study were DO and BOD. Thailand has established the national freshwater standard DO and BOD values since 1992. These standard values take into account the percentile DO and BOD levels, which are 6.0 and 1.5 mg/L, respectively (Ministry .of Science, Technology and Environment-MSTE 1992). The optimal goal of setting these standard values is to safeguard inland water quality for aquatic biota and human consumption.

Largely, the water samples collected from the Cheon had DO and BOD that met the standard values. But when considering DO and BOD values between stream sites, these two variables had shown clear water quality impacts. The waters in impacted sites had relatively lower DO content (Fig.2.6) and higher BOD (Fig.2.7) than the less disturbed sites.

The fluctuation of DO values between sites was closely correlated with two combined factors; seasonal regime and SS. During heavy rainfall, the stream sites located in the cleared lands were much impacted from surface runoffs, thus yielding very high SS levels. The diffused sediment further caused the DO depletion within the water column.

The Cheon waters had low BOD value (mean 1.4 mg/L), which fell within the natural water range ($\leq$ 2.0 mg/L, Chapman and Kimstach 1992).

Like DO values, the BOD of the Cheon waters varied between sites. The impacted sites from land clearing had high BOD levels (Fig.2.7). In this instance, diffused sediment from the land surface is the major cause of high BOD within the water column.

The results from UPGMA identified that SS and PO_4 were the two most significant water quality impurities of the Cheon waters. Both values were derived from diffused sediment and more intensive agriculture, particularly in the stream sites located in cleared lands. The magnitude of water quality impact in the Cheon was greatest during the first rainy month, April.

The Cheon headwater streams clearly showed water quality impacts related to land use. Streams located in cleared lands received much input from diffused solids which led to high BOD and low DO levels. The waters in streams situated in forested land were less impacted from surface runoffs, resulting in high DO and low BOD. These two water quality parameters are important determinants which influence benthic macroinvertebrates (Table 2.4).

Environmental impact: the presence of indicator taxa

The most striking feature between the reference and impact sites is that the reference site has a large number of taxa different from the disturbed sites. Disturbed sites with different degrees of impact also had different taxa composition.

Both sensitive and tolerant taxa were restricted to different sites and times. Among the macroinvertebrate fauna, Trichoptera was the most distinctive order which was more abundant in site A than any other sites. There were some trichopterans limited only to site A: *Amphipsyche meridiana*, *Cheumatopsyche malaysiensis*, *Tinodes* sp., *Stenopsyche siamensis*, *Hydrochyche* sp., *Neureclipsis* sp. and *Synaptopsyche klakahana*. Most of these taxa were found during December, the post-flooding period with a rather cool climate. These larvae built fixed retreats on cobbles and large pebbles. The waters in site A during December were very clean with a high DO level of 8.3 mg/L, and a moderate current speed of 0.9 m/sec. In this instance, it suggested that the presence of these caddisfly taxa was associated with seasonal regime, DO and forest cover.

Some caddisfly taxa in site A showed a periodic occurrence following seasonal regime. *A. meridiana* was the first species which appeared only after the post-flooding period. The emergence of *A. meridiana* was also reported in recovery streams after floods in Indonesia (Boon 1984). Similarly the hydropsychids *C. malaysienensis* and *Hydropsyche* sp. were also found in site A after the rainy season. These two filter–feeder taxa began to build up their fixed retreat on submerged cobbles in site A. These taxa were classed as mildly to moderately tolerant by Roux *et al.* (1992). However, in this study these two taxa were abundant only in site A with relatively clean waters. It suggested that the presence of these taxa was still related to mild perturbation.

Another distinctive caddisfly in site A was the ecnomid *Neureclipsis* sp. This net-spinning species is also sensitive to organic pollution (Hellawell 1986). During this study, this species was found to inhabit only site A.

Other net-spinner caddisflies *Tinodes* sp. and *S. siamensis*, both preferred to inhabit in cool, shaded streams with a high DO level in site A. These two species were rare in this catchment, but the first species was abundant in pristine streams in Phukradueng National Park (Chapter 6), 50 km from the Cheon. *Tinodes* sp. was found to build its fixed retreat on bedrock and submerged large cobbles in pristine streams, while *S. siamensis* made its silk filtering net only on cobbles. Surprisingly, the *S. siamensis*, thought to be restricted to Huay Prom Lang stream in Nam Nao National Park, 40 km from the Cheon (Sangpradub 1996, unpublished document). But there were very few *S. siamensis* individuals found in the Cheon and they were mostly restricted to site A.

Although almost no studies to date associate any single caddisfly species with environmental factors in the Asian tropics, the restriction of these net-spinner taxa to site A may indicate pristine water conditions. Further, the existence of these caddisflies clearly showed the significance of forest cover to the streams and adjacent lands.

Consequently, studies into the influence of land clearing on stream waters might use the presence of net-spinner caddisflies as a biological indicator.

Like caddisflies, mayflies also showed remarkably different distributions between sites. Some mayfly taxa found only at site A, were very rare in impacted sites. *Potamanthus* sp. (Potamanthidae) was particularly abundant in site A. The BMWP score (Hellawell 1986) assigned a score of 10 (highly sensitive) to all Pothamantidae species and Lenat (1993) classed *Potamanthus* sp. as a sensitive species to water pollution. This species was very common sprawling on the stream bottom in site A, but rarely found in other sites.

Other noteworthy mayfly taxa were *Heptagenia* sp. (Heptageniidae) and *Ephemera* sp. (Ephemeridae), which were found in various sampling months in sites A to D. The most striking feature was that these taxa were found only in streams where the waters had a high DO level. These two mayfly taxa are widespread and recognised elsewhere as sensitive taxa which require highly dissolved oxygen (Hilsenhoff 1988).

Unlike caddisflies, the distribution of these two mayfly taxa was not strongly related to forest cover or land clearing, but rather reflected the dispersion of microhabitats with high DO levels within the streams. This suggests that, within a modified stream reach, there may be still certain microhabitats that could be occupied by these high oxygen-requiring nymphs. It further emphasises the biological significance of microhabitat heterogeneity as recently emphasised by other investigators (e.g. in

Hildrew and Giller 1992, Downes, Lake and Schreiber 1993). Disregarding the abundance between sites, the simple presence and absence scoring of these taxa at a site then has more limited use.

Only one water beetle species, *Cleptelmis* sp (Elmidae), demonstrated that its occurrence was related to the degree of impact between sites. Elmidae, even in Great Britain, was classed as a moderately tolerant species, but in tropical Asia, Jach and Kodada (1995) noted that most elmid species could be used to indicate good water quality. This is reinforced by this study since the riffle beetle *Cleptelmis* was more abundant in high-oxygenated waters both in riffle and run areas in site A.

Unlike the above mayfly nymphs, *Cleptelmis* sp. was mostly limited to site A, and like net-spinning caddis flies, is a member of the indicator fauna of high DO and good forest cover condition.

Stoneflies are another group commonly used to indicate good water quality (Baumann 1979, Harper 1994). However, stoneflies were very rare in this catchment, and only two species were discovered, *Neoperla* sp. and *Phanoperla* sp. (Perlidae). *Neoperla* sp. is widespread (Sivec 1984) whereas *Phanoperla* sp is abundant in tropical Asia (Harper 1994). Perlidae has been claimed to be a family sensitive to pollution (Hilsenhoff 1988, Stewart 1992). There are very few studies about nymphal stonefly ecology in Asia and only limited information is available, mainly from Malaysia (Bishop 1973) and Hong Kong (Dudgeon 1982, 1984).

This study has found that quantifying water quality impacts by the presence of the perlids, at genus or family level, was less reliable. Perlids were found in both less impacted (site A) and impacted downstream site (site E). The waters in the first site when Perlidae was found, in October, April and June, were relatively clean, with a BOD range of 0.7-0.9 mg/L and EC of 110.9-178.4 μS/cm. While in the lower site E, this family was found only in December, when the waters were comparatively degraded, BOD 1.3 mg/L and EC 498.0 μS/cm (the BOD measures the organic impurity and the EC roughly signifies the inorganic impact). Given this situation, the presence of perlids could not be universally used to infer any aquatic pollution occurring here.

Uchida (1990) and Harper (1994) reported that Asian Perlidae occupied both highland and lowland streams and were well adapted to environmental changes. Harper (1990) further noted that the use of perlid species as pollution indicators was unlikely to be appropriate in the Asian region.

However, there are some conclusion which can be drawn from the occurrence of Perlidae in the Cheon catchment. Firstly, as Perlidae often occurred in cooler sheltered waters, they may be indicative of water temperature. Secondly, at genus level, *Neoperla* was mostly limited to less impacted site A while the *Phanoperla* was widespread. Thus, the presence of *Neoperla* could indicate more pristine stream conditions. Nevertheless, with its limited numbers, *Neoperla* would be a less pragmatic bioindicator than the more abundant sensitive caddisfly and mayfly individuals.

In contrast to the sensitive taxa approach, the presence of tolerant taxa at a site was found to be another valuable indicator capable of differentiating degrees of impact. This study confirmed the status of Oligochaeta, Ceratopogonidae and Chironomidae as pollution indicator taxa, as all three were abundant at impacted stations.

Of the three tolerant taxa, *Bezzia* sp. (Ceratopogonidae) demonstrated a unique response to flooding episodes by increasing in numbers predominantly during the first storm month, particularly in site C, the site with much diffused nutrient input. *Bezzia* then became the species that indicated the impact from "fresh" nutrient discharged from land runoffs. This species was reported as pollution tolerant, and particularly from inundation (Neckles, Murkin and Cooper 1990).

Molluscs were another taxon abundant in some sites, but was never found in the control site. Upratham *et al.* (1995) recently reviewed the taxonomy and distribution of gastropods in Thailand, but their ecology and association with pollution is still poorly known in this region. However, the molluscs found here, to some extent, could indicate the magnitude of sediment deposit. There were two findings that were closely associated with different degrees of sediment input and accumulation along the river length and between streams. Firstly, along the river length, the filtering collector molluscs, particularly the bivalve *Corbicula brandina,* were abundant downstream while less common in upstream sites. Secondly, within similarly situated upstream sites, bare sites had more molluscs while the forest site (A) had no molluscs. The different magnitude of sediment at a site and between sites could therefore be reflected by the presence and abundance of molluscs.

Environmental impact: the implication of macroinvertebrate density

Quantifying freshwater catchment impacts using the presence of indicator taxa was quite a promising approach as discussed above. The density data, in addition, allowed more rigorous analysis. The less impacted sites A and D had the highest individual density in the cool month of December, while the impacted sites had the greatest individual density in the first rainy month of April. The less impacted sites were dominated by caddisfly and mayfly taxa, while the impacted sites were dominated by dipterans, Oligochaeta and molluscs.

Macroinvertebrate individual density fluctuated markedly following the seasonal climate, largely due to the flooding regime. Within a site, the variation of individual density through time showed a clear relationship with physical water properties, especially discharge, SS and turbidity. Between sites, differences in individual densities were associated with land use and the nature of the riparian buffer strip. The dominant cause that dramatically reduced the individual density was land clearing which led to the elevated water discharge and high SS and turbidity within water column. Finally, the habitat was altered and became unsuitable for macroinvertebrate colonisation as previously found by Dudgeon (1994).

Differences in individual densities between and within sites were apparent. Individual colonisation within a site both in forest and bare sites featured similar contiguous distributions with taxa aggregated in response to streambed heterogeneity. This distribution type is claimed to occur whenever sampling benthic macroinvertebrate within a stream reach (Elliott 1978). Analysis of differences in benthic macroinvertebrates between stream sites must be done carefully (Hildrew and Giller 1992) because any attempt to compare inter-site differences using individual density is meaningless if the intra-site variability is much greater.

However, in this study the results showed that the intra-site difference was less than any inter-site difference based on quantitative multiple habitat sampling. Of course, it is possible that if sampling was limited to one habitat type, for example cobble, this regime may produce a different result from that of multiple habitats. Also, this may pose the problem of sampling a large number of individuals of certain taxa specific to the cobble habitat, while having minimal individuals of non-cobble prefering taxa. Substrate size is one of the most prominent factors that determine the extent of individual density of a single species (Quinn and Hickey 1990).

However, the study found that not only substrate sizes *per se,* but also the microhabitat alteration can be significant. Whereas the four upstream sites (A-D) all had similar substratum type (mixed bedrock, cobble, pebble and silt/clay), the substrates in impacted sites were largely covered with silty clay, while the substrates in less impacted sites supported a flourishing periphyton. It was this difference which was in part responsible for difference in individuals, and taxa richness found between sites, even though all sites had the same substrate character.

Difference in the density of caddisfly, mayfly and true fly individuals were significant between sites. Caddisfly and mayfly individuals were denser in less impacted sites than impacted sites, whereas Chironomidae, Ceratopogonidae, and Oligochaeta, were denser in impacted sites.

Generally, the total individual density data from multiple habitat sampling can reflect the magnitude of impacts on sites. More precisely, a high individual density of certain taxa, particularly caddisfly and mayfly, can indicate more pristine water at a site, whereas high individual densities of Chironomidae, Ceratopogonidae, and Oligochaeta, on the other hand, signify more degraded stream sites.

Although there is some promise in using the single presence or absence of caddisfly and mayfly taxa in assessing environmental impacts, individual density data was found to be more informative. The presence and absence measure may be appropriate for rapid assessment, provided it has been calibrated against individual density data.

Classification and ordination results

The indicator taxa produced by the TWINSPAN classification also confirmed the outcomes when using individual density data as discussed above. Both pollution tolerant and sensitive taxa indicated by the TWINSPAN showed a clear relationship with the magnitude of special and temporal impacts at a site.

Indicator taxa from the TWINSPAN provide invaluable information as these taxa strongly relate to the environmental impacts between samples/sites. For example, Figure 2.11 illustrates the classification results from all samples combined from all months and sites, and it is very difficult to separate samples within groups 3 and 4 if using taxa richness and individual density data.

The existence of indicator taxa, for example, *Bezzia* sp., led to the discrimination between samples groups 3 and 4. The presence of *Bezzia* sp., signifies the environmental impact occurring in samples/sites, as in the case of site C which has *Bezzia* sp. abundantly present (255.6 specimens/m^2) in February when the waters were severely polluted with maximum levels of BOD, EC and TDS, 4.3 mg/L, 313.5 µS/cm and 208.5 mg/L, respectively.

The impact of discharge and SS from overland flow on taxa composition in each TWINSPAN group is also obvious. For instance, samples of group 3 (Fig. 2.11), in particular, had relatively less polluted waters and had high sensitive taxa richness, such as trichopterans: *Goera* sp., *Hydroptila* sp., *Tinodes* sp., *Molanna* sp., *Anisocentropus* sp., *Chimarra* sp., *Oxyethira* sp., *Triaenodes* sp.; the coleopterans: *Cleptelmis* sp., *Dineutus* sp.; the ephemeropterans: *Thraulodes* sp., *Ephemera* sp., *Paraleptophlebia* sp., *Heptagenia* sp., and the dipteran: *Simulium* sp.

A useful outcome of the TWINSPAN anayses are the "indicator taxa" since these are taxa which can be used to help characterise particular groups of sampling sites which possibly share similar environmental conditions. These are not to be confused with indicator or sensitive taxa which are nominated to indicate levels of pollution on the basis of their tolerance to gradients of impacts, although they could often be the same. The term "sensitive species" is generally applied to various caddisfly and mayfly species based on tolerance values, mostly from Great Britain and North America.

TWINSPAN effectively classified the less impacted and impacted samples/sites, and both density and presence/absence data contribute almost the same results. However, the TWINSPAN using presence and absence data reveals a more refined identification between samples/sites affected by natural causes. The ordination results also conformed to the TWINSPAN output, identifying those samples/sites which were impacted, as well as the indicator taxa produced by the two methods. This similarity in output suggests these data sets may be used interchangeably in multivariate analyses.

Overall conclusion

Degradation of the Cheon headwaters is apparent on evidence from both water physicochemistry and the macroinvertebrate fauna. The physicochemical parameter that most strongly reflects this degradation is SS. Other water quality variables are less prominent, except for high PO_4 levels during the first rainy month of April. This is unsurprising given that land runoff and SS are normally associated with an increase in phosphate levels in streams. The macroinvertebrate data more accurately reflected these impacts in the Cheon than did water physicochemistry. However, these two measures are obviously correlated given the sensitivity of some species to environmental conditions.

A combination of factors correlates with change in the fauna at various scales in the Cheon. On a catchment scale, the landscape gradient and channel morphology are major correlated factors, whereas on a more local scale, riparian buffer strip width, land use category, suspended solids and discharge are prominent. The latter sources are crucial and interrelated, and finally, are influenced strongly by land use (Dudgeon 1988, Ormerod *et al.* 1993, Richards, Host and Arthur 1993, Barling and Moore 1994, Carter, Fend and Kennelly 1996).

The presence and absence of indicator taxa is a useful criterion to assess the magnitude of environmental impacts between streams. The variation of individual density among sites, both by total or each taxa group, is more rigorous, and can be used to confirm the presence and absence measure.

Classification and ordination methods identify clear environmental impacts influenced by both natural and human causes. Indicator taxa produced by both methods assist in efficiently summarising the biological impact occurring at a site.

Finally, the study results suggested that quantification of environmental degradation in tropical catchments requires a comprehensive sampling design. This is because the tropical climate features strongly contrasting seasonal conditions: high-low flows, hot/dry vs. heavy rain. The repeated sampling procedure through time and space as recommended by some authors will yield much more robust results (Stewart-Oaten *et al.* 1986, Underwood 1991, Underwood 1993, Dudgeon 1995).

There are certain recommendations, which will assist the rehabilitation of the Cheon freshwater ecosystem:

(i) Conservation of the existing stream buffer strip and rehabilitation planting of native vegetation along all of the Cheon stream banks.

(ii) Encouragement and support to the community to grow perennial fruit crops rather than seasonal crops.

(iii) Promotion of land contouring to minimise overland erosion.

(iv) Information dissemination to the community regarding stream conservation.

CHAPTER 3

Spatial and Temporal Distribution of the Benthic Macroinvertebrate Community of the Pong Catchment, Northeast Thailand: The Significance of Seasonal and Human Impacts

Introduction: aquatic macroinvertebrate studies in tropical Asia

Little research into the human impacts on ecological systems in tropical catchment rivers has been done (Gopal 1993, Dudgeon 1995). Recently, a group of interested limnologists sought to raise interest in the problems and future research needs for conservation and management of tropical Asian and Australian inland waters (see discussion and details in Dudgeon *et al.* 1994). They concluded that our knowledge and understanding of changes in tropical river ecology in both Asia and Australia is very limited, although there are some studies in progress. In particular, they noted that extensive biological research aimed at understanding changes in the ecosystem health of freshwaters in tropical Asia and Australia is still a fundamental need (details in recent review by Dudgeon 1995).

Publications on freshwater biology in tropical Asia are rare. Aspects of the macroinvertebrate fauna have been addressed in a limited number of research projects in Hong Kong, India, Malaysia, Sri Lanka, Nepal and China, and almost all these studies relate to small streams in cool mountainous areas (Bishop 1973, Dudgeon 1982, 1984, Benzie 1984, Bhatt *et al.* 1985, Answar and Siddiqui 1988 and Brewin 1995). Certainly, the use of macroinvertebrates in assessing water resources and ecosystems, as is routine in Europe and North America, is very limited in tropical Asia to date.

The use of biological methods in assessing river degradation, particularly organic pollution is not new, and has a history of almost a century in Europe (Metcalfe 1989). Various biological indices and scores for assessing water quality have been created and several workers have attempted to modify those measures for their own countries (Washington 1984, Metcalfe 1989).

Among those indices, species diversity and community similarity are the most reliable measures, while biotic indices are most applicable to particular geographical areas (Washington 1984). Such biotic indices and score systems as, for example, BMWP/ASPT (The Biological Monitoring Working Party Score System/Average Score per Taxon) and the Belgian Biotic Index and Indice Biologique Global France, are still widely used and adapted in many countries in Europe. These indices in fact largely utilise the macroinvertebrate fauna as bioindicators for assessing water pollution in continental Europe.

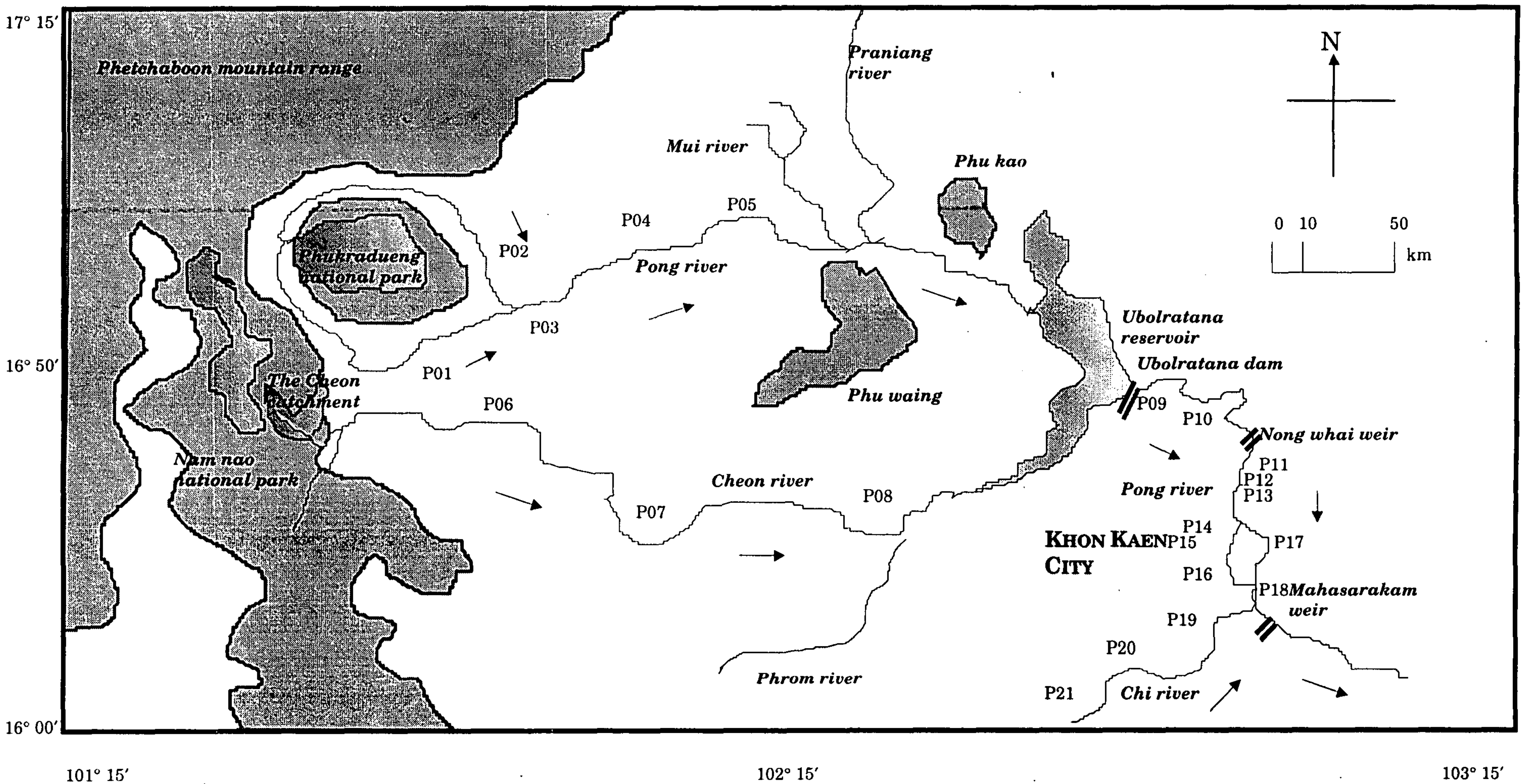


Figure 3.1 Sampling sites of the Pong catchment northeast Thailand (Phu means mountain, map redrawn from KKU 1995)

Below the Ubolratana dam, the waters form into a single channel, still called the Pong river, which eventually reaches a second dam, the Nong Whai weir, which was established for rice field irrigation. The waters are abstracted and channelled from both sides of this weir supplying all the rice farms which are located in the middle Pong catchment. The Pong river then flows into the lower catchment where the land is devoted to mixed intensive uses and occupied by industries and a large urban centre, Khon Kaen, with a population of 240,000. The Pong river is finally joined by the Chi river, a little beyond Khon Kaen city boundary (Fig. 3.1). The Pong waters further flows past the Mahasarakam weir. This newly constructed weir was finished in 1995 to store and regulate waters inter-linking with the Ubolratana dam upstream.

Sampling site description

Twenty-one sampling stations were established across the Pong floodplain. These were chosen to give a cross-section of the major land use patterns in the catchment as well as having reasonable access for sampling. Sites P01-P08 are in the upper floodplain above Ubolratana Dam, while sites P09-P21 are located in the lower catchment area (Fig.3.1).

Sampling sites P01 and P02 are fourth-order streams which receive waters from the Phukradueng National Park headwaters. Sites P03 to P05 are located in the fifth-order river reaches where most of the adjacent land is used for mixed cropping. Sites P06 to P08 are fourth-order streams on the Cheon river where the lands around these sites are mainly modified for rice paddocks.

Of the middle catchment part, sampling sites P09-P10 are located along the Pong river reaches below the Ubolratana dam. Near these sites, is located the largest pulp-paper mill factory in southeast Asia close to the Pong river bank. This factory discharges its treated effluent into the river between sites P09 and P10 (Fig.3.2). Sites P11 to P13 have their stretches located beyond the Nong Whai weir to the point where the river splits into two channels.

Sites P14 to P16 are located on the Prakuea river (the local name of one of the Pong river splits), within the Khon Kaen city boundary in the lowest part of the Pong catchment. The river waters receive discharge mainly from city sewage, particularly the river reach from sites P15 onwards. Site P17 is located in another channel of the Pong river, and receives mostly suburban sewage, and to some extent, rice farm run-off. The final sampling site on the Pong river is P18 located above the confluence of the Pong and Chi rivers, approximately 5 km above the Mahasarakam weir.

Sites P19 to P21 are on the Chi river, also located in the lowermost part of the catchment region. These sites are affected by substratum rock salt intrusion which becomes severe during summer months. These sites are also located in suburban Khon Kaen where many subdivisions for housing are currently being established.

The sampling stations may be conveniently grouped, according to their geographical location, into three zones. Sites P01-P08 are in the upper catchment, while sites P09-P13 and P14-P21, respectively, are of the middle and lower catchment areas. Table 2.1 shows some of the major topographical characteristics of all sampling sites (Fig. 3.2).

Table 3.1 Topographical characteristics of sampling sites

Site	Location	Altitude (m.s.l)	River	Distance from source (km)
Upper				
P01	16° 48′ N, 101° 49′ E	274	Pong	50
P02	16° 52′ N, 101° 53′ E	213	Ponggo	53
P03	16° 50′ N, 101° 56′ E	208	Pong	62
P04	16° 52′ N, 102° 10′ E	121	Pong	105
P05	16° 49′ N, 102° 20′ E	106	Pong	123
P06	16° 30′ N, 102° 04′ E	128	Cheon	89
P07	16° 29′ N, 102° 07′ E	113	Cheon	121
P08	16° 29′ N, 102° 25′ E	98	Cheon	142
Middle				
P09	16° 45′ N, 102° 40′ E	94	Pong	154
P10	16° 43′ N, 102° 46′ E	92	Pong	159
P11	16° 42′ N, 102° 50′ E	91	Pong	173
P12	16° 36′ N, 102° 50′ E	90	Pong	195
P13	16° 29′ N, 102° 53′ E	88	Pong	224
Lower				
P14	16° 26′ N, 102° 52′ E	87	Pong	261
P15	16° 26′ N, 102° 54′ E	86	Pong	268
P16	16° 26′ N, 102° 57′ E	85	Pong	275
P17	16° 25′ N, 102° 58′ E	88	Pong	278
P18	16° 25′ N, 102° 58′ E	84	Pong	292
P19	16° 24′ N, 102° 59′ E	91	Chi	256
P20	16° 24′ N, 102° 56′ E	89	Chi	241
P21	16° 22′ N, 102° 52′ E	83	Chi	222

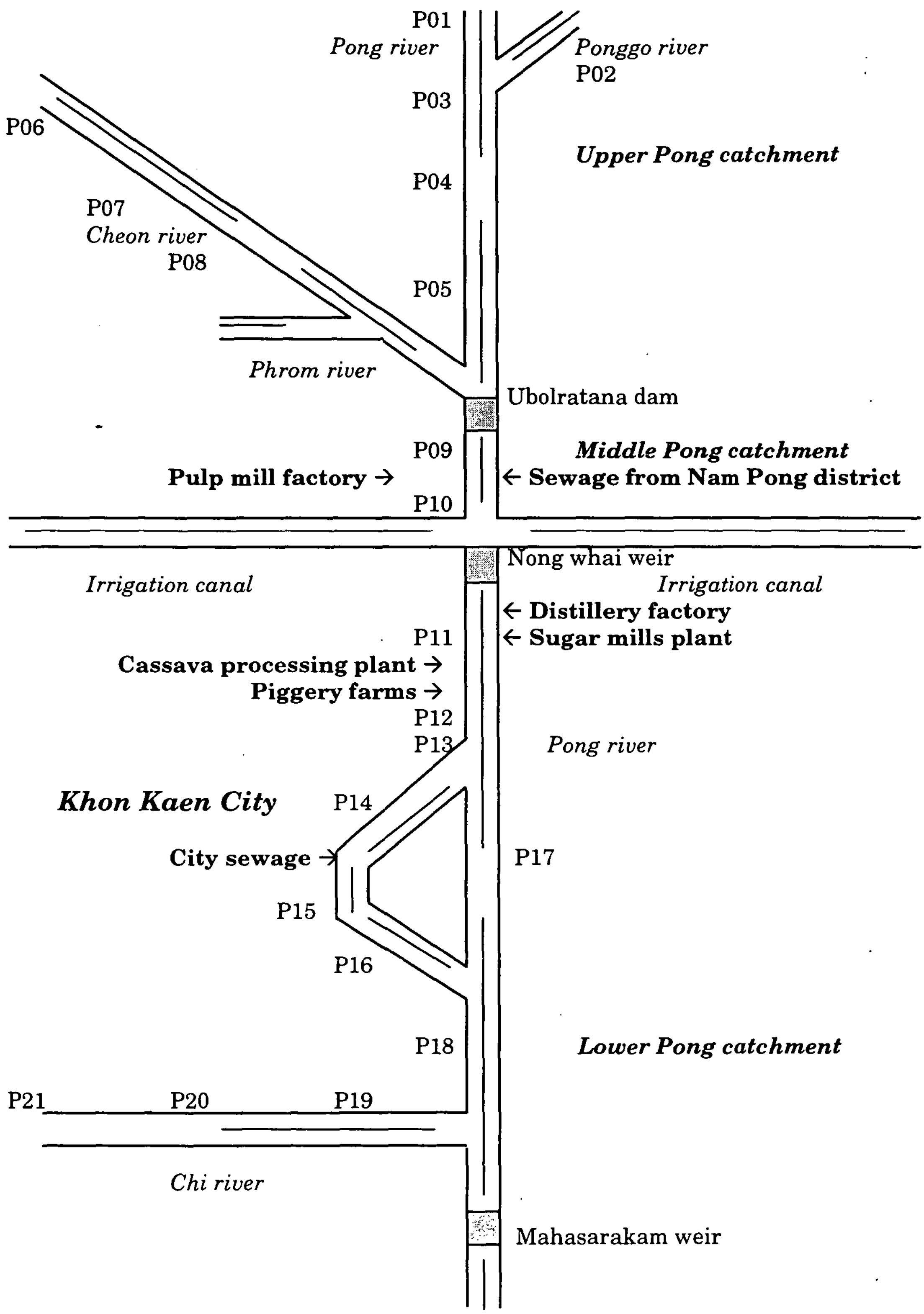


Figure 3.2 Diagrammatic summary of the sampling sites and major point-source discharges in the Pong catchment watercourses

There are different magnitudes and types of impact which affect the Pong catchment waters (Fig.3.2). In upper catchment areas where most of the lands are cleared for rice fields, the river waters of the Cheon and Pong rivers mainly receive seasonal surface-runoffs from rice paddocks.

In the middle catchment, the waters are affected by mixed industrial and community effluent, while in lower catchment areas, the river waters are impacted mainly by city sewage outfalls. In the lowermost catchment where sites P19-P21 are located, the waters are influenced by salinisation from dissolved rock salts and with a lesser degree of community sewage discharged from subdivision housing. All major point-sources which affecting the Pong waters are summarised in Fig.3.2.

Materials and methods

This study was conducted in two calender years, between February 1995 and August 1996. Water pysicochemistry and benthic fauna were sampled bimonthly from all sampling sites, P01-P21, except sites P07 and P17 which were added later in 1996.

At each site, a uniform river stretch of approximately 100 m length is marked and six sample units are randomly located within each site. Sampling upstream shallow sediment used a Surber sampler while in lowland downstream waters an Ekman Grab was employed from a boat. Water physicochemistry, flow rate and river dimension are sampled, measured and analysed following the methods described in Chapter 2.

Methods of water and animal sample preservation follow similar methods already described in Chapter 2. Water physicochemistry variables analysed were velocity, depth, width, discharge, temperature, pH, alkalinity, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), turbidity, phosphate (PO_4), nitrate (NO_3), dissolved oxygen (DO) and biochemical oxygen demand-5 day (BOD), chloride (Cl) and sulfate (SO_4).

The access to laboratory equipment was supported by three Departments, namely Biology, Sanitary Science and Civil Engineering, of Khon Kaen University, Thailand. Laboratory and field assistants were provided by Department of Biology, Khon Kaen University and Department of Health, Ministry of Public Health, Thailand.

Data analyses

Water physicochemistry and benthic data were analysed by univariate and multivariate methods. Spatial and temporal data were analysed by analysis of variance (one-way ANOVA), regression and correlation tests in the SPSS statistical package (SPSS 1994). Water quality and benthic fauna data sets were classified and ordinated using the PATN package (Belbin 1995).

Raw data of average taxa density from all six replicates was transformed to log (x+1). Water physicochemical data was standardised by X-Mean/SD prior to analysis by multivariate methods (Singer 1980).

The Unweighted Pair Group arithMetic Averaging (UPGMA) method was used to cluster the sites based on water physicochemical and faunal data sets (Sneath and Sokal 1973, Gauch 1982). Ordination of sites used Semi-Strong Hybrid MultiDimensional Scaling (HMDS) via the Bray-Curtis association measure (Marchant 1990, Clarke 1993), while water physicochemical data applied the Euclidean distance association matrix.

Correlations between UPGMA benthic faunal groups and water physicochemical variables were determined by Discriminant Function Analysis (DFA) using the Discriminant option in SPSS (1994) (Norris and Georges 1993).

Significant benthic species and water quality variables were correlated to the sites ordination space using Principal Axis Correlation (PCC option in PATN). The 100 Monte Carlo Randomisation is permuted to test the statistical significance of such benthic species and water chemical variables correlated to the HMDS ordination space (MCAO option in PATN). The significance level applied throughout the study used 95% confident interval, unless otherwise specified.

Presentation of results

The results presented in this Chapter will be subdivided into minor sections in which each section focuses on individual themes but are interrelated.

Section 1. Climatic variation and aquatic environmental changes

Climatic variation

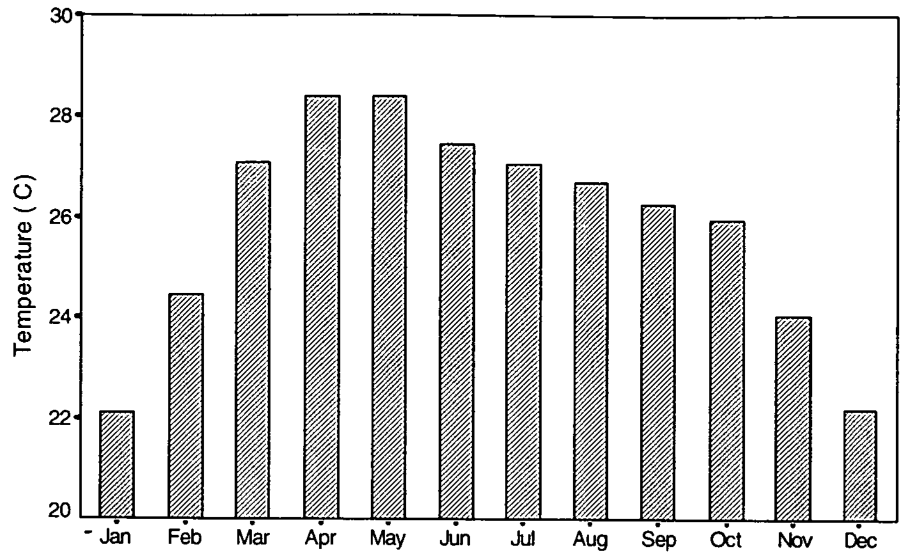
The Pong catchment has a tropical monsoon climate, with contrasting dry and wet seasons. Like other parts of southeast Asia, the wet period extends from late May to October each year when the southwesterly monsoon from the Indian ocean brings rainfall to the Pong catchment. In the dry season, between November and early May, the local climate is under the influence of northeasterly winds from inland China. Within the dry season, the climate within the Pong catchment can be further subdivided into hot and cool periods. The cooler period extends from November till late February, while the hot period extends from March till early May. The most comprehensive climate data relates to Khon Kaen city in the middle part of the catchment and is summarised here.

The mean air temperature varies markedly between months (Fig.3.3a). In March, the air temperature begins to rise, reaching a peak in April and May when it averages 28.4 °C. The average lowest air temperature is in December at 22.2 °C. The evaporation pattern follows the air temperature profile (Fig.3.4). Evaporation peaks during the hottest month of April, averaging 213.2 mm. Each part of the catchment has a slightly different average air temperature, probably reflecting elevation. It is lower in the upper catchment (25.2 °C) than the middle and the lower parts, which are 25.8 and 26.4 °C respectively.

Rainfall within the Pong catchment varies markedly between months and locations (Fig. 3.3b). September is the wettest month when average rainfall reaches 266.9 mm, whereas December averages only 2.7 mm. Average monthly rainfall within the Pong drainage basin is 104.4 mm.
The upper catchment has higher rainfall at 111.8 mm per month averaged over the year, than the middle and lower parts, 103.0 and 98.4 mm, respectively. The initiation of the wet season also differs within the catchment. In the upper catchment the rain begins in April, while in the middle and lower catchment, the first rain is not until May.

The different initial wet months between parts of the catchment is reflected in the magnitude of corresponding vegetated areas. The upper Pong catchment has an extensive area of forested land connected to the Phetchaboon mountain range, while in the lower catchment the land ha long been cleared for crops (Fig.3.1).

(a)



(b)

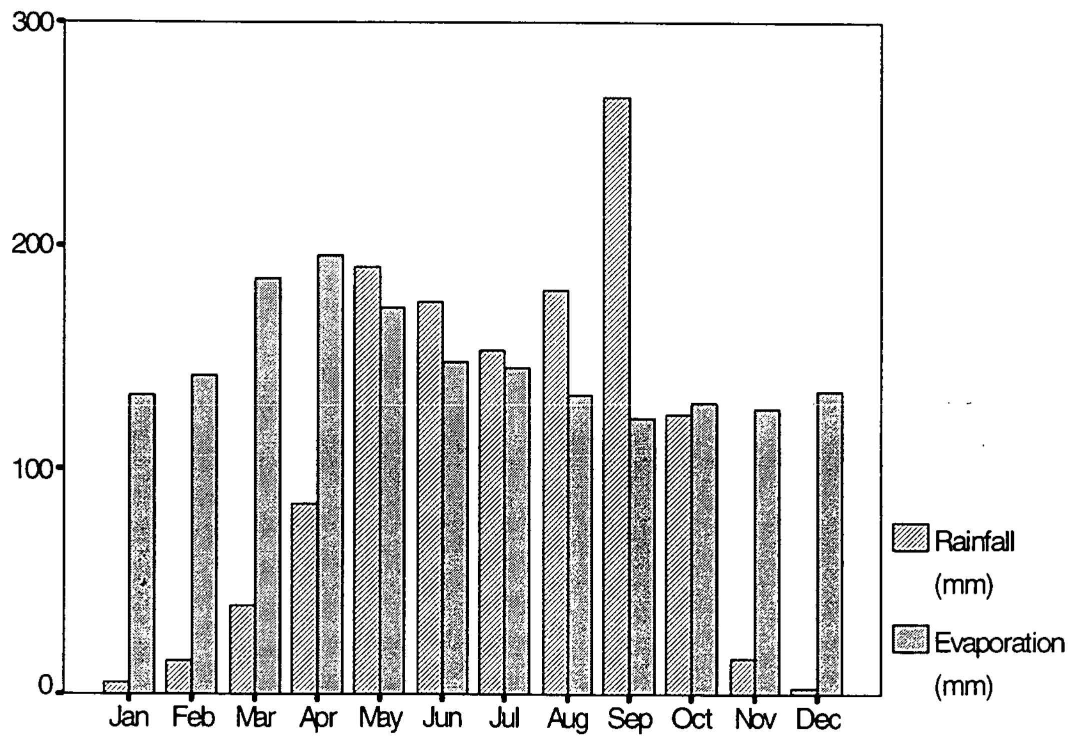


Figure 3.3 Average monthly levels of (a) temperature, and (b) rainfall **and evaporation within the Pong catchment 1962-1995 (Meteorological Department-Thailand, 1996)**

Water quality variation within the Pong floodplain

Water discharge within the Pong catchment fluctuates due to a combination of factors, primarily landscape topography, seasonality of the rainfall and river regulation. Average annual discharge differs markedly between catchment zones. The upper catchment sites have a lower average annual discharge level, 20.4 cu.m/sec, while the middle and lower catchment stations have 101.8 and 74.6 cu.m/sec ($F_{2,200}$=8.245, P<0.001). Water discharge also differed between sampling sites ($F_{20,182}$=2.321, P<0.01), while most sites in the downstream catchment have higher water flows. Site P10 located between the Ubolratana dam and Nong whai weir (Fig.3.4a and see also Fig.3.1), had the highest discharge, averaging 175.6 cu.m/sec.

Of the three factors which influenced river water discharge, seasonal regime plays a major role in varying water discharge within the catchment. The river flow is very different between wet and dry seasons ($F_{1,201}$=20.212, P<0.0001). The average river discharge in the dry season is 24.6 cu.m/sec, while in the wet season it is four times higher at an average of 97.0 cu.m/sec.

Total suspended solids (TSS) within the water column also varies significantly in relation to the catchment gradient ($F_{2,200}$=5.559, P<0.01). The upper catchment sites (P01-P08) have relatively higher TSS levels, particularly during rainy months, averaging 138.8 mg/L. The sampling sites locating in the middle and lower catchment parts have lesser TSS levels, averaging 12.9 and 42.3 mg/L respectively.

Such high TSS levels in the upper catchment subsequently cause turbidity within the water column. Accordingly, the upper sampling sites have significantly higher turbidity levels (95.9 NTU) than the middle and lower catchment sites, which are 10.6 and 61.1 NTU consecutively ($F_{2,200}$=8.841, P<0.001). Water turbidity has a strong contrast between seasons, being higher in wet season, averaging 79.7 NTU, while in the dry season it decreases to 43.5 NTU ($F_{1,201}$=5.081, P<0.05).

Within upper catchment sampling sites, sites P01, P03 and P04 have relatively high turbidity when compared to other sites, an average of 132.4, 169.7 and 123.7 NTU, respectively. This is mainly because the riverbanks of these sites have relatively high slope (~30%), and most of the lands are cleared for cassava and sugar cane plantations. Sites P09, P10 and P11 which are located immediately below the dam/weir in contrast, have the average lowest turbidity levels, which are 6.0, 5.9 and 4.7 NTU, respectively. The water columns at these two sites are deeper and have a slower current speed compared to other sites.

Unlike TSS, TDS level increases significantly along the catchment profile, Fig. 3.4a ($F_{2,200}$=23.959, P<0.0001). The waters of middle catchment sites have relatively lower TDS (average 161.7 mg/L), while the upstream sites have slightly higher average TDS values (170.7 mg/L). A marked increase in TDS level clearly appears in the farthest downstream waters as these sites (mean TDS level 365.2 mg/L) are much influenced by both sewage and saline intrusion.

The effect of city sewage which causes high levels of TDS is obvious in the comparison between sites P15 and P17 (Figs. 3.1 and 3.2). These two adjacent sites are located on the same plain but receive different amounts of city sewage outfall. Site P15 has an average TDS level more than twice as high as site P17 (318.8 mg/L vs 144.9 mg/L). Sites P14 to P16, which are located within the city area, show remarkably high TDS levels, which decline in the downstream sites, P17 and P18 (Fig. 3.4a). The last three sites P19 to P21 have comparatively high TDS average levels, which are 422.0, 497.3 and 557.4 mg/L respectively but are mainly affected by rock salt dissolved from the local substratum. The major ion which contributed to the high TDS level in these sites when tested was chloride.

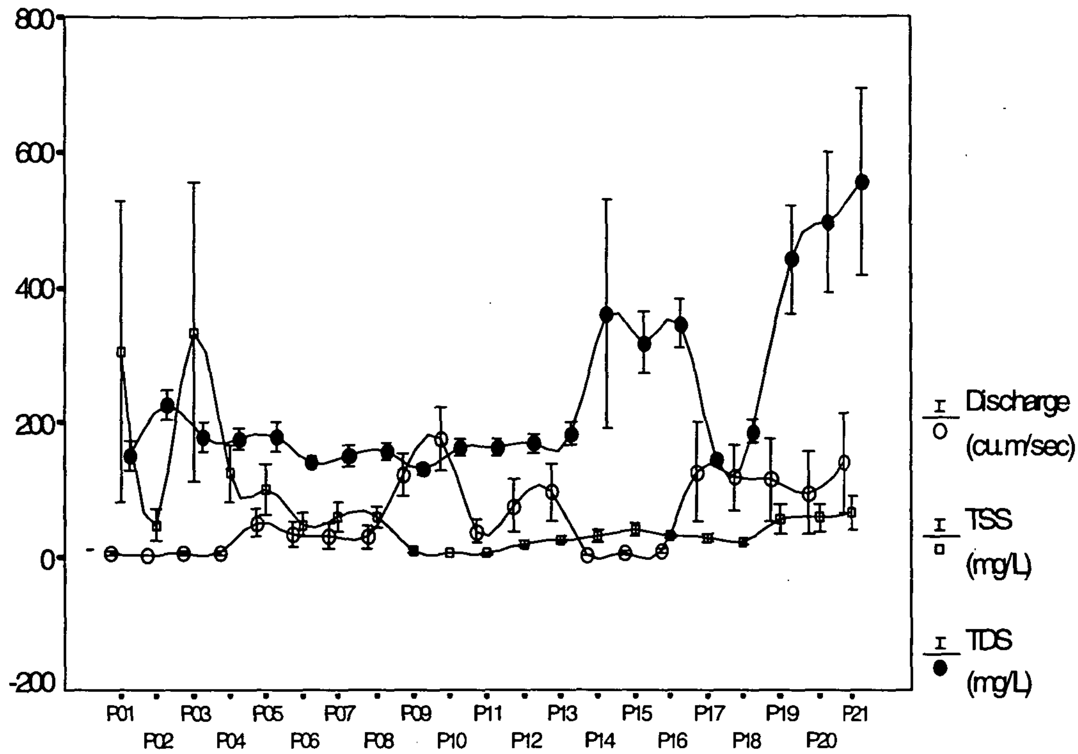
There is a marked chloride gradient along the catchment ($F_{2,143}$=20.261, P<0.0001). Water from the upper catchment (average 7.4 mg/L) and middle sites (14.3 mg/L) had low chloride contents but in the lower catchment sites, the chloride level became very high, averaging 115.1 mg/L.

Chloride levels in sites P19 to P21 were high at 149.9, 171.7 and 192.4 mg/L, respectively, so that the waters of these sites may be classified as brackish. The chloride problem caused by salt intrusion in this area is especially severe during the dry season. For example, in site P21 even the waters in the dry season appear to be less organically polluted, but the chloride level rises very high with an average of 350.1 mg/L. This leads to high EC and TDS levels with their maximum levels of 1428.9 μS/cm and TDS 919.9 mg/L, respectively.

Chloride ion content was highly variable even between some adjacent sites. Sites P14 to P16, in particular, had relatively high chloride levels (155.9, 99.5 and 100.2 mg/L, respectively), whereas sites P13, P17 and P18, located in the same vicinity, had much lower chloride levels (18.9, 22.9 and 27.9 mg/L, respectively).

Another sets of water quality variables that their levels are clearly fluctuating within the Pong catchment watercourse are BOD and DO. The Pong river which flows across the city areas shows relatively low DO content but the highest BOD level (Fig. 3.4b).

(a)



(b)

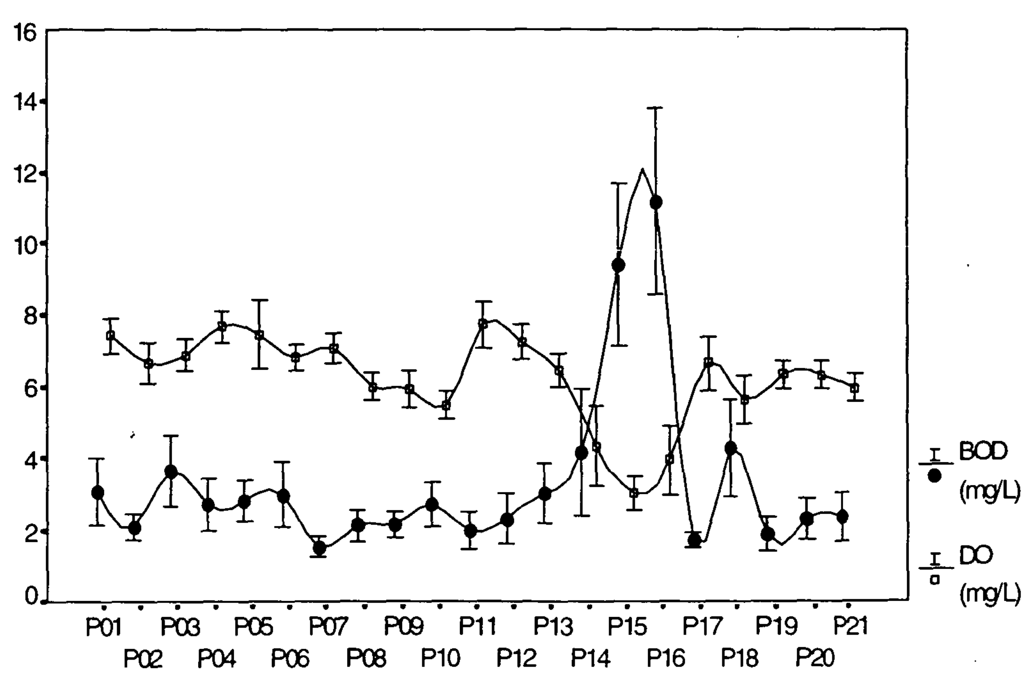


Figure 3.4 Spatial water physicochemical quality levels of the Pong catchment (a) water discharge, TSS and TDS, and (b) DO and BOD (mean±SE)

The catchment waters, in general, suffered from extreme BOD levels during the dry season, averaging 4.3 mg/L and a low BOD level in wet season while drops to 2.6 mg/L ($F_{1,201}$=8.999, P<0.01). Site P16 in particular during dry season is severely impacted by organic BOD content, averaging 15.2 mg/L (Fig.3.4b). The BOD values increase significantly along the catchment profile ($F_{2,200}$=7.462, P<0.001). The upstream sites on the average have lower BOD level than the lower catchment sites.

The remarkably highest BOD level frequently occurs in site P16 during dry month, its average NO3 and PO4 values are also very high with the average of 4.8 and 0.7 mg/L, respectively. This is mainly from city sewage discharges.

All of the water quality variables of the lower Pong waters are strongly influenced by community sewage discharges which induce high BOD content in waters (see also Fig. 3.2).

Apart from the influence of city sewage inflow to the Pong river, the effect of waterlogging by dams due to DO level is also apparent. Sites P09 and P10, in particular, have lower DO levels when compared to other upstream sites, Fig. 3.4b (see also Fig. 3.1).

Dissolved oxygen content in waters, generally differed between the sites ($F_{20,181}$=4.276, P<0.001). The upstream sites have relatively higher DO level than the middle and lower catchment sites, which average 7.0, 6.6 and 5.2 mg/L, respectively ($F_{2,199}$=16.015, P<0.0001).

A zone of self-purification along the Pong river is apparent in relation to the DO content (Fig. 3.4b). At sites P09 and P10, the DO level begins to decline as waters are degraded by damming and the discharge from a large pulp mill factory (Fig. 3.2). However, a certain trend of self-purification is revealed by a higher average DO level downstream at site P11. Later, from sites P13 to P16, the DO levels gradually decrease, as the river is further polluted by wastes discharged from factories and communities.

In contrast to sites to P16, the waters in a tributary split from the Pong but not directly flowing through Khon Kaen, has a high DO level, as measured at site P17 (Figs. 3.1, 3.2). Both tributaries are later joined and the water quality eventually recovers to a normal state by site P18.

Alkalinity and nutrient levels also change along the Pong watercourse. Upstream sites have higher alkalinity level than downstream sites ($F_{2,200}$=23.288, P<0.0001). The average alkalinity (as $CaCO_3$) in waters of upper catchment sites is 123.8 mg/L, while those of the middle and lowermost sites are 93.4 and 86.2 mg/L, respectively.

However, some downstream sites also had high alkalinity levels. Sites P15 and P16, on the average had 114.9 and 109.8 mg/L, consecutively. The higher alkalinity levels in upstream sites are mainly naturally due to carbonate rock salts while those of the lower sites are from community source. In the latter case, for example, site P15 during dry season has the highest average alkalinity level, 125.4 mg/L. Also, this site had high average levels of BOD (13.12 mg/L), TSS (53.3 mg/L) and turbidity (40.8 NTU). The waters at this site were mostly stagnant in the dry season with an abundance of blue-green algae. The high alkalinity in this case is mainly from the shifting of the carbonate-bicarbonate equilibrium caused by eutrophic condition rather than by carbonate substrates in upstream sites.

Nutrient levels measured by PO_4 and NO_3 values of all sampling sites were spatially significantly varied. Phosphate levels differed significantly between sites ($F_{20,182}$=3.144, P<0.001). The downstream sites had high PO_4 level, averaging 0.12 mg/L, but sites P15 and P16 had particularly high levels which averaged 0.25 and 0.42 mg/L, respectively. Observation made during summer months showed that the waters were very polluted with heavy algal blooming. These two sites also had distinctly high NO3 levels, which averaged 1.12 and 3.57 mg/L, respectively. High nutrient levels at these sites were caused by community sewage.

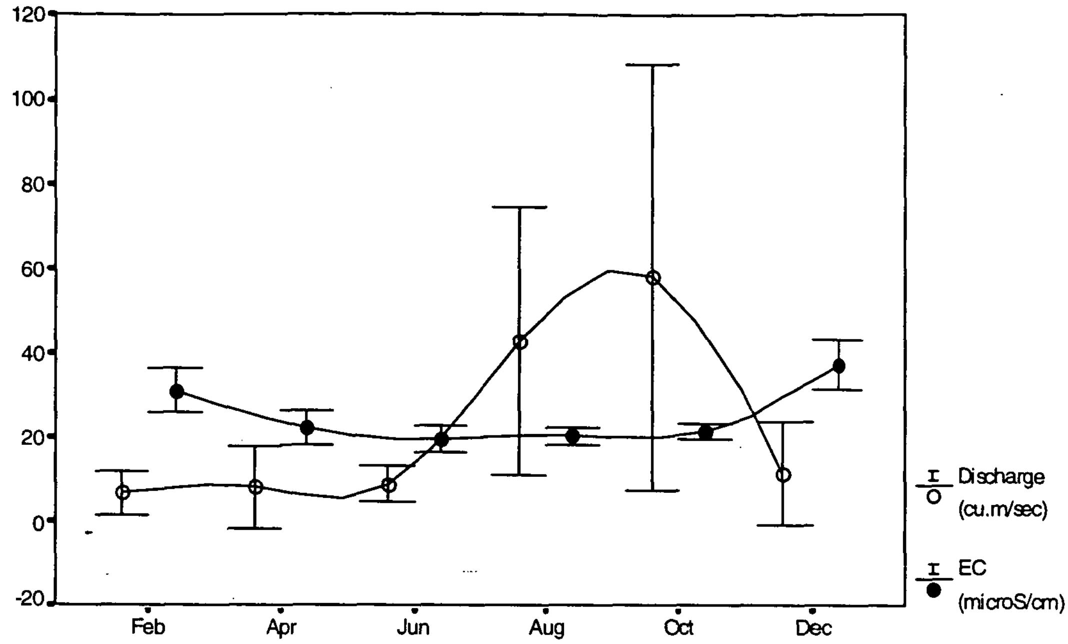
Temporal water quality variation

Water quality within the Pong catchment varies markedly in response to the annual climate, especially as it affects discharge. Water discharge begins to increase in June, reaches a maximum during October (Fig.3.5a) and affects all water quality parameters. During periods of high discharge, most pollutants within the water column are diluted, particularly the BOD level (Fig.3.5b). In April, the hottest month, the mean catchment BOD level reaches its maximum, while the average DO is at its lowest level.

In the upper catchment the weather starts to change in April with the arrival of occasional rains and the initiation of run-off from the land which leads to rising TSS levels in the water column is detected at this time. However, these levels in lowland areas remain temorarily low leading to marked differences in TSS levels along the catchment during April (Fig.3.6a). Similarly, the average water velocity of the catchment gradually increases during late April and returns to a normal state in December (Fig.3.6a).

The average EC level is very much diluted following high discharge, and becomes high in the low-flow period (Fig.3.5a). The average levels of dissolved nutrients, NO_3 and PO_4, are higher during the period of low discharge (Fig.3.6b). In high water flow period, the nutrients are progressively diluted to an annual minimum during October.

(a)



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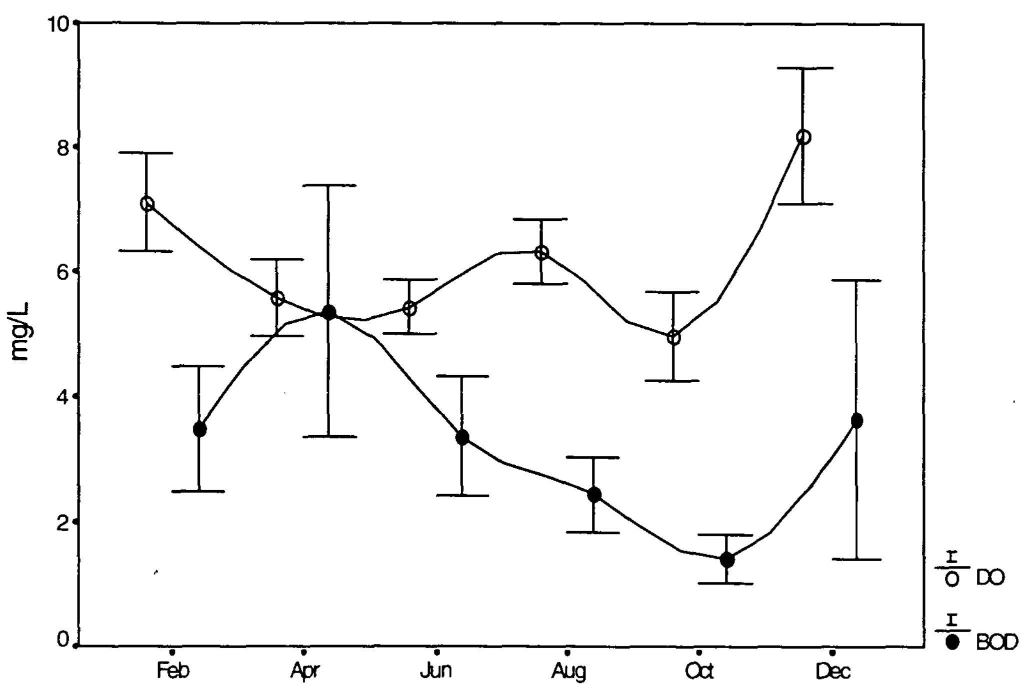
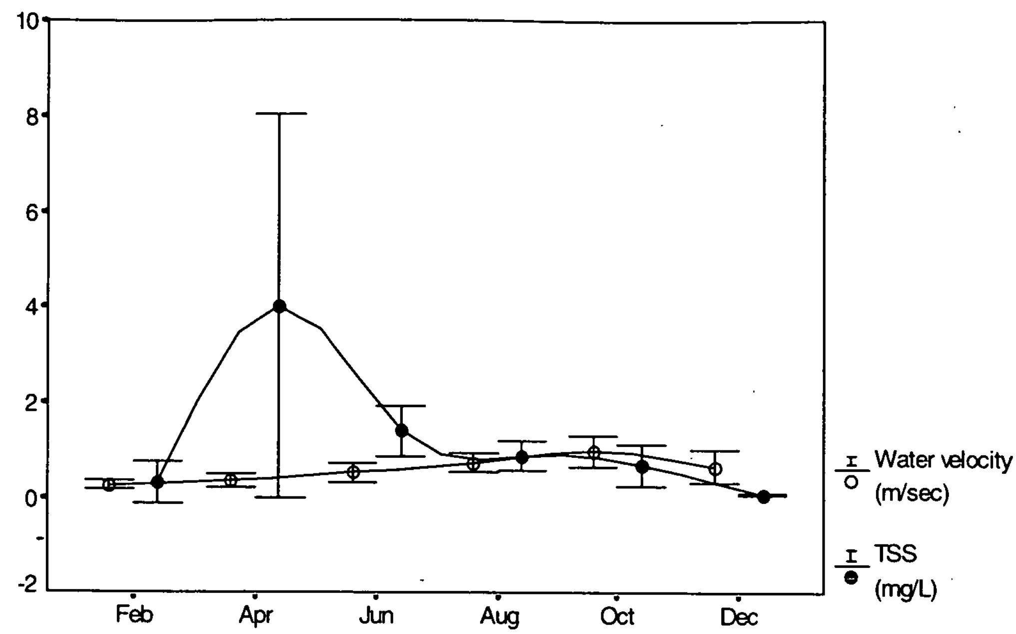


Figure 3.5 Bimonthly variations of (a) water discharge, EC ($x10^{-1}$), and (b) DO and BOD

(a)



(b)

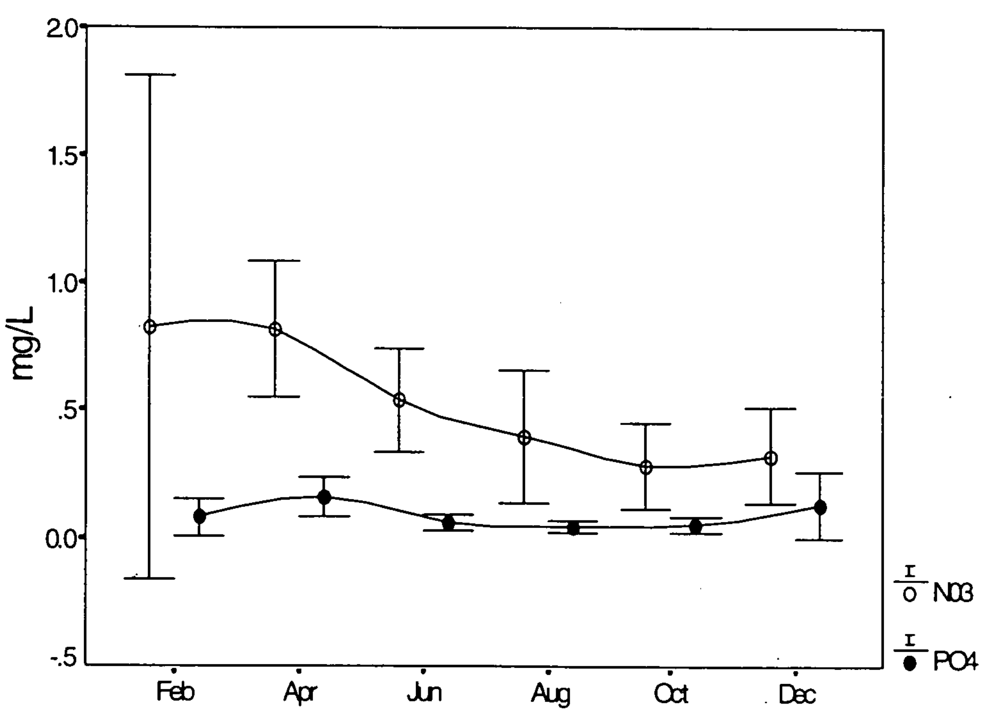


Figure 3.6 Bimonthly variations of (a) water velocity, TSS ($x10^{-2}$), and (b) NO_3 and PO_4

Catchment water quality analysed by multivariate methods

Figure 3.7a shows the relationship between the sites from ordination and classification methods. The upper catchment sites clearly locate together (P01 to P09), while the middle sites (P09 to P13) and the distinct downstream sites (P19 to P21) both are well separated. Sites P14 to P16, which receive high organic pollution from city sewage, are well isolated from other site groups.

Most sites clustered by UPGMA on physicochemical data are arranged in the ordination space somewhat following the catchment geographical gradient. However, the grouped sites P14 to P16 with high negative scores on Axis 2 do not conform to the landscape profile. The biplot from the ordination analysis alone, however, shows some sites visually overlapping. These are sites P05 and P08, which are geographically located immediately above the Ubolratana dam (Fig.3.1).

Significant water quality variable vectors which correlate to the ordination space are shown in Fig.3.7b. It is clear that upstream sites show certain impacts from high suspended solids in water column and also with water velocity. These sites also have high DO values and alkalinity. The sites located where waters are impacted by local rock salts clearly show a typical signature in the strong EC, chloride (Cl) and TDS values. The BOD, NO_3 and PO_4 vectors are obviously directed to the sites located near the city which receive heavy amounts of sewage input.

Initial summary of water quality impact

A brief summary of water quality variation in the Pong catchment during the two-year study (1995-1996) is:

(1) Water quality is relatively good in the upper catchment part, while in the downstream lowlands it is substantially degraded.

(2) Dry season water quality in the Pong catchment is critical and susceptible to organic pollution, particularly at river stretches located close to large communities.

(3) BOD and nutrients (NO_3 and PO_4) were major pollutants in the lower catchment, while the upper catchment had higher suspended solids from surface runoff.

(4) Major organic pollutants retained during summer are all diluted and ameliorated by natural rainfall in the wet season.

(5) Ordination and clustering based on water quality data identify the most polluted sites as distinct outliers.

(a)

(b)

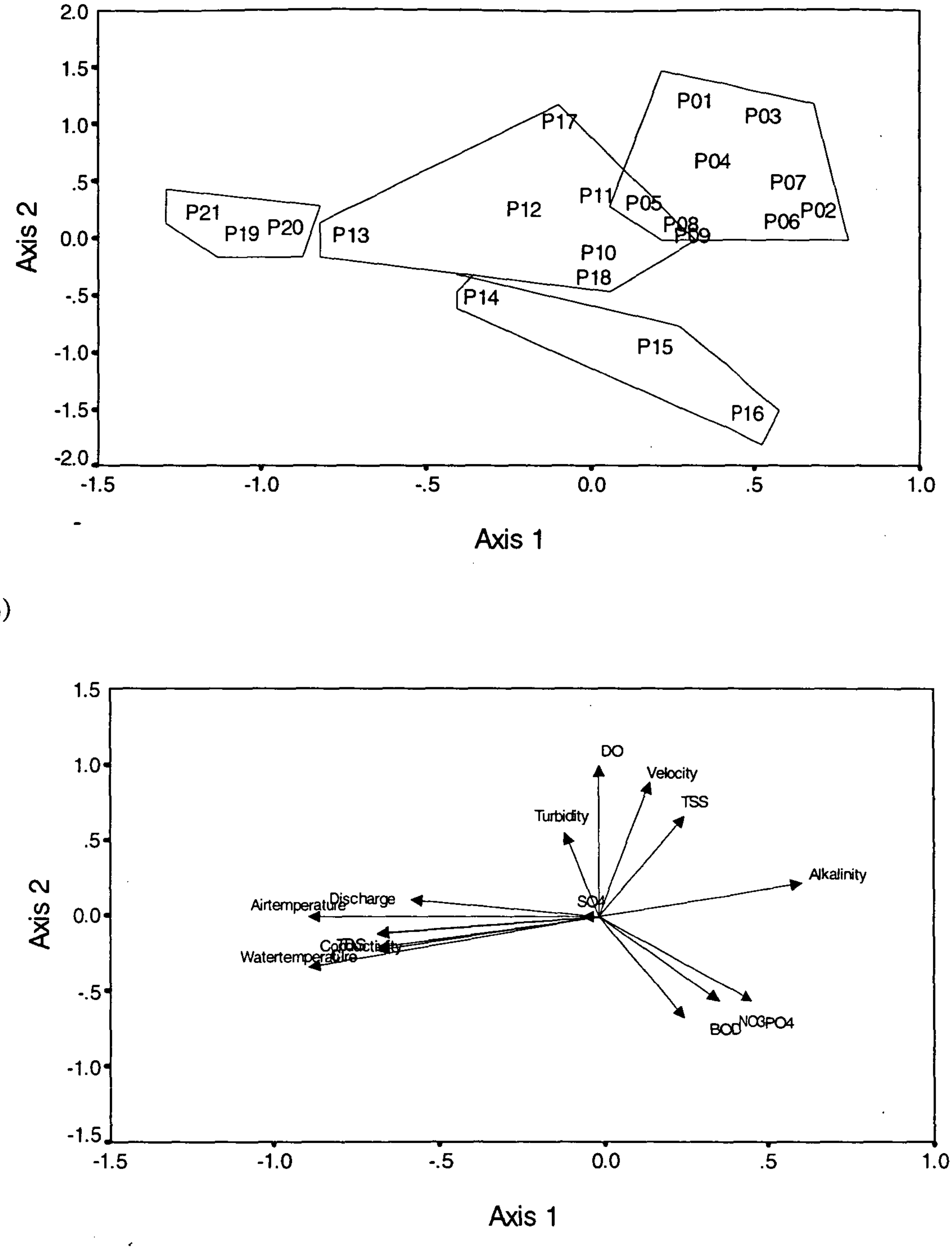


Figure 3.7 Ordination results based on average annual water quality data (a) sampling sites ordination by HMDS (stress 0.1102), grouped sites in polygons marked clustered by UPGMA, and correspondingly, (b) physicochemical variables significantly correlated to the ordination space.

Section 2. Spatial and temporal benthic taxa distribution

Catchment benthic macroinvertebrate abundance

A total of 136 benthic taxa and 30,032 individuals were recovered during the two-year sampling. These belonged to 24 families in 12 orders. Chironomidae midge larvae and Oligochaeta are each counted as single taxa. The most species rich order was the Odonata with 27 species. Water beetles and caddis flies ranked equal second in richness with 24 species each. Figure 3.8 shows the species richness per order found in all sampling sites.

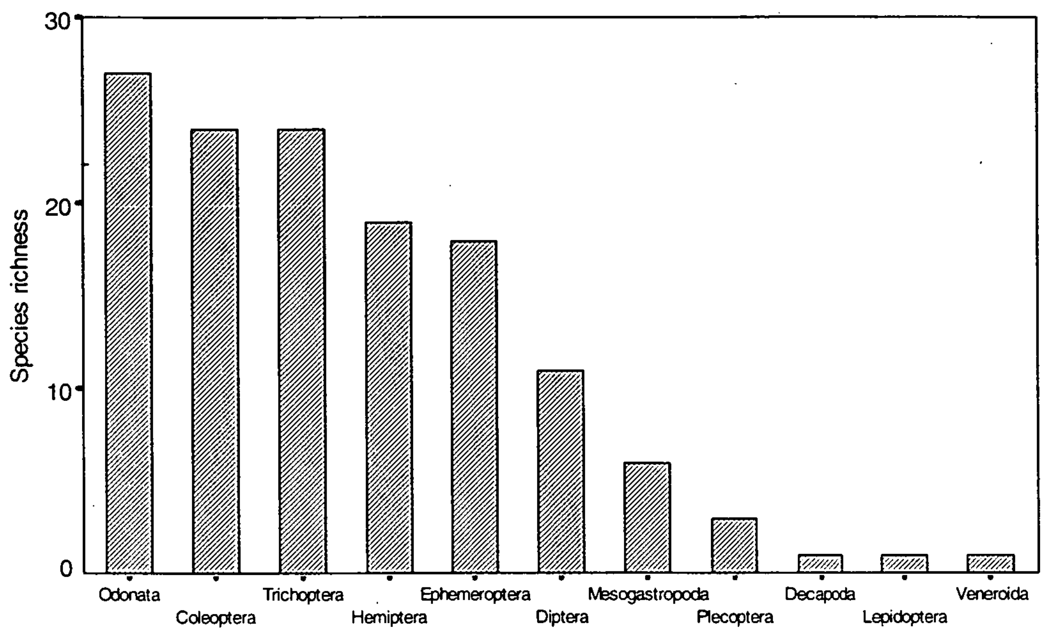


Figure 3.8 Species richness per order sampled during 1995-1996 in the Pong catchment Thailand

Spatial distribution of benthic macroinvertebrates

There is a marked difference in benthic macroinvertebrate species richness and density along the Pong catchment gradient (Fig.3.9). The upper catchment sites had higher species richness (115 species) than the middle and lower catchment sites (65 and 42 species, respectively). In contrast, densities of individuals were higher in the middle and lower catchment sites, which on the average, had 200.2 and 169.0 individuals/m^2, respectively, while in upper catchment sites, the mean density was 57.5 per m^2.

Figure 3.10 shows species richness and taxon composition at each sampling site. Species numbers are higher in the less impacted sites P01 to PO4, while the sites influenced by damming, industrial and community sewage discharges have lower taxon richness.

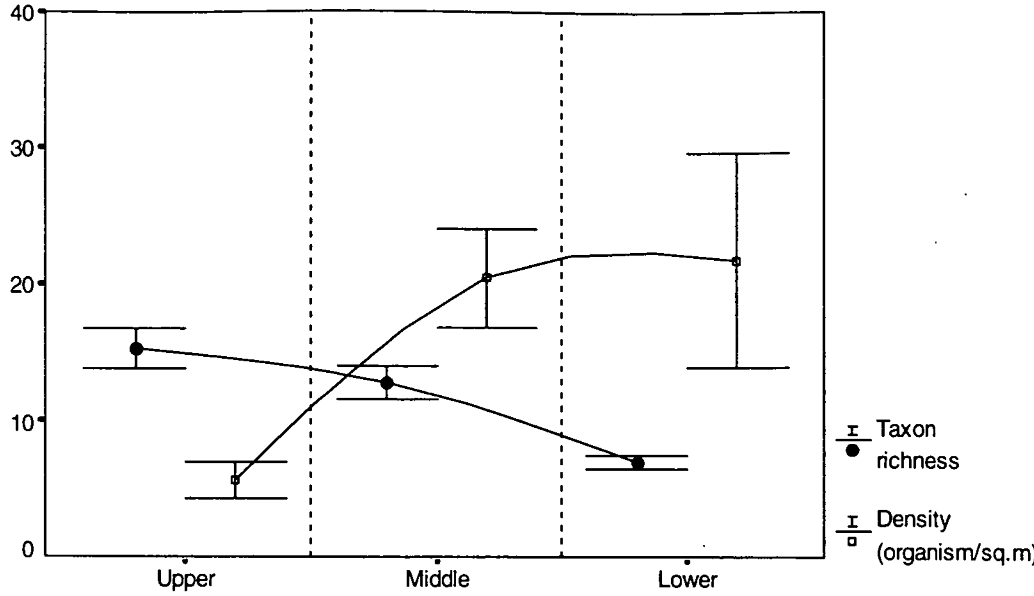


Figure 3.9 Taxon richness and individual density ($x10^{-1}$) of benthic larval assemblages classified by subcatchment areas (mean±SE)

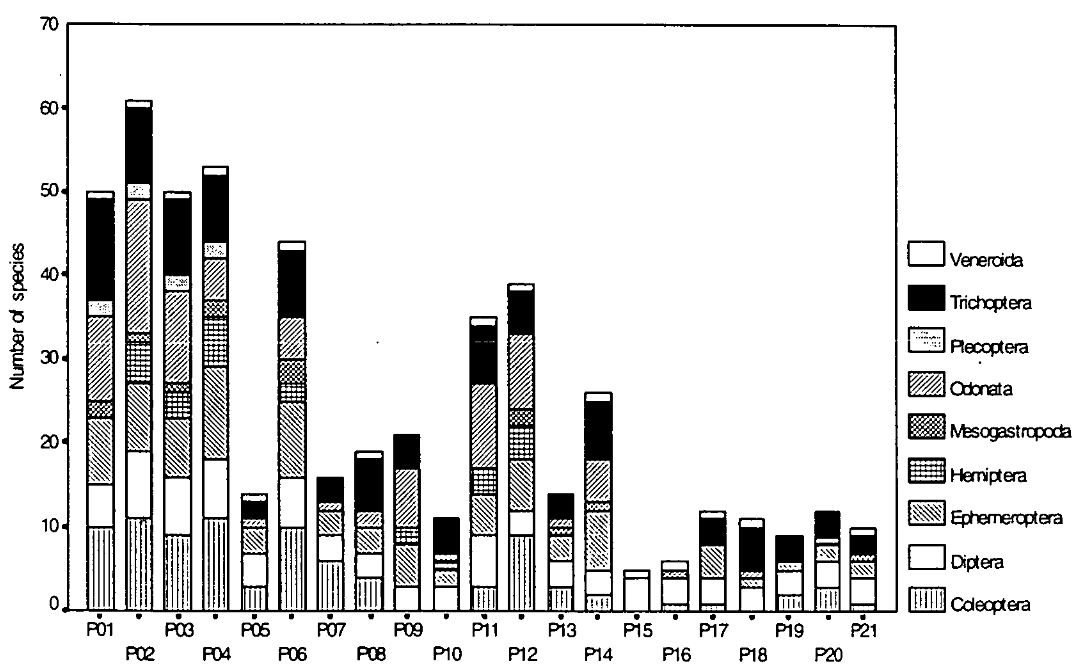


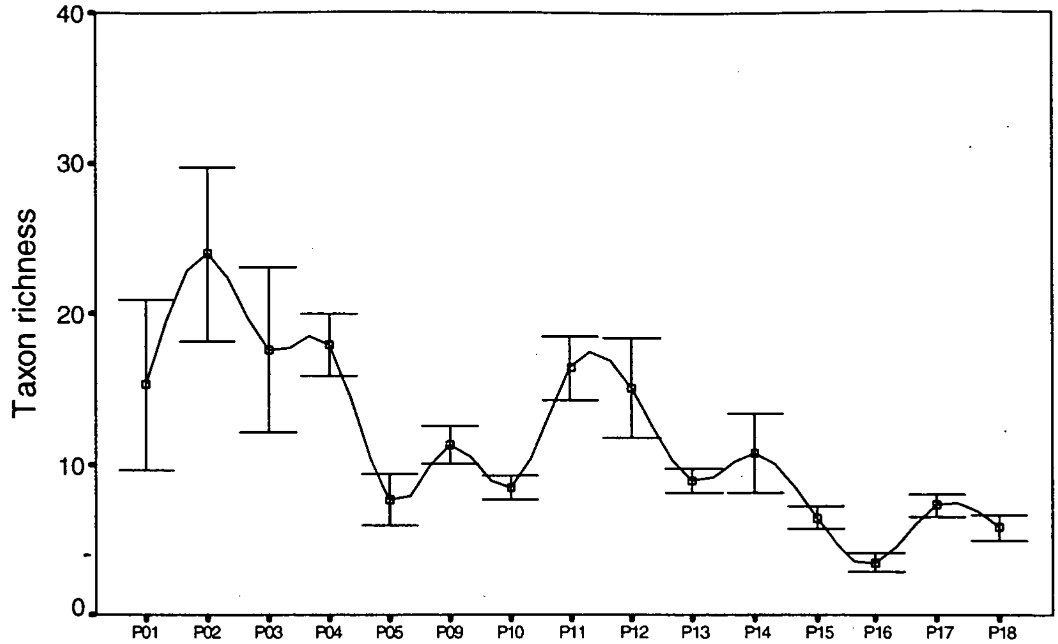
Figure 3.10 Species number composition of selected major taxa groups in all sampling sites

The species richness is higher in some lower catchment sites (P11 and P12). The species composition is also different between upper and lower catchment sites (Fig.3.10). For instance, in upstream sites their benthic macroinvertebrate taxa mostly consist of Trichoptera, Ephemeroptera, Odonata and Coleoptera. In downstream sites the proportion of these species is decreased. Appendix 3.1 gives more details of species in each subcatchment zone.

Within the Pong waterway, benthic macroinvertebrate species richness is greater in upstream sites with less human disturbance than in middle and lower catchment sites influenced by dams, city sewage and industrial sources (Fig.3.11a). Site P02 has maximum benthic species richness of 63 species. Site P15, in contrast, has minimal species richness of 6 species.

Invertebrate individual density is much higher at downstream sites than at upstream sites (Fig.3.11b). Site P19 has maximum density of macroinvertebrates, averaging 552.4 organism/m^2. Site P01, the uppermost sampling site has the least average density of 22.4 organism/m^2.

(a)



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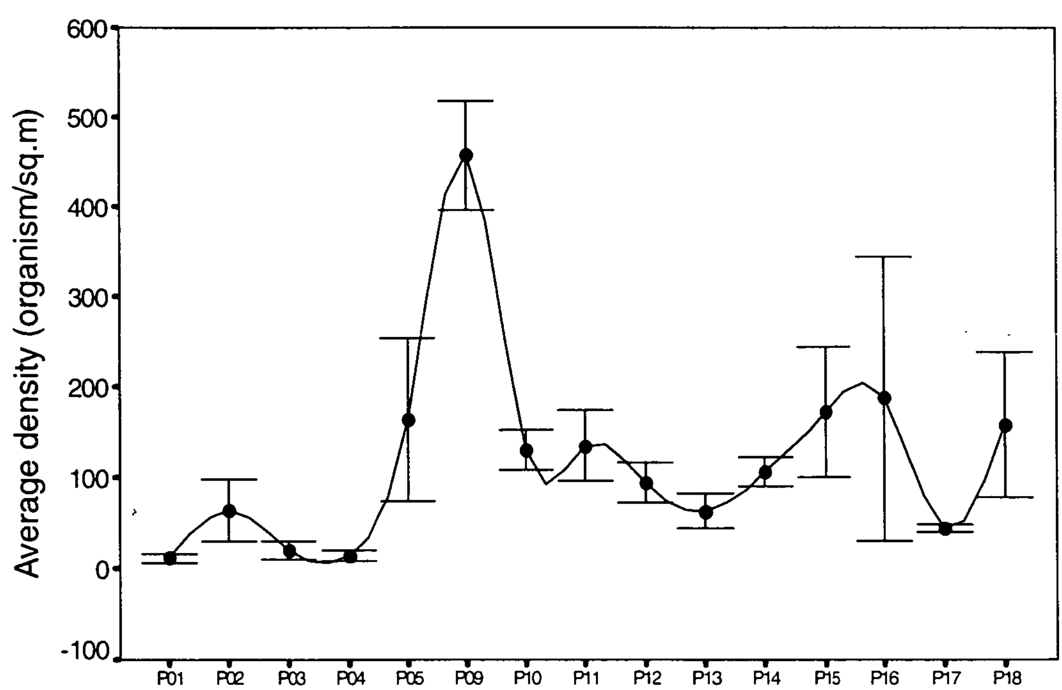


Figure 3.11 Macroinvertebrate fauna (mean±SE) of the Pong river (a) species richness, and (b) individual density

Temporal benthic macroinvertebrate taxa variation

Most benthic larvae reach a peak in abundance in February and begin to decline towards the wet season. Figures 3.12 and 3.13 illustrate the cumulative number of benthic larval species and their average density per order based on bimonthly sampling. In August, both species richness and density of most benthic macroinvertebrate fauna reach an annual minimum.

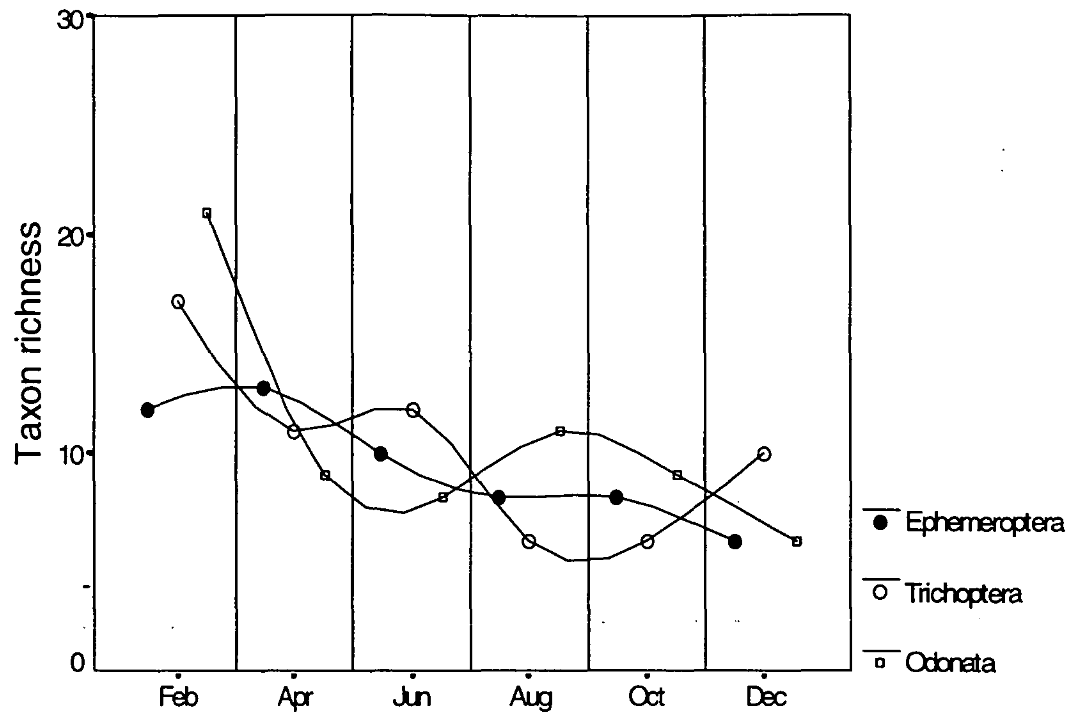
The orders Ephemeroptera, Trichoptera and Odonata well illustrate the downward trend in abundance from February to December (Fig.3.12a). However, the phenology of a few taxa deviates from this general pattern. Mayflies, in particular, reach their maximum abundance in April (Fig.3.12a). During late April, when the first rains begin in upper catchment areas, mayflies achieve their greatest species richness (13 species) although at low individual density (21.5 individuals/m^2).

The most abundant mayflies during the early monsoon are ecologically sensitive heptageniids and leptophlebiids, including *Arthroplea* sp., *Heptagenia* sp., *Choroterpes* sp. and *Habrophlebiodes* sp. Two taxa, *Arthroplea* sp. and *Habrophlebiodes* sp., are found only in April.

In June, when water volumes are increasing, the mean mayfly density reached its annual maximum (83.0 organism/m^2) (Fig.3.12b). At this time the ephemerid *Litobrancha* sp., which apparently prefers high water levels throughout the Pong catchment, becomes the predominant mayfly with a mean density of 180.5 organism/m^2. Another mayfly species which exists almost everywhere, except in severely polluted sites, is *Caenis* sp1. It is very abundant in upstream sites and was also found in downstream waters, and appears to increase in numbers after the waters return to a normal state from heavy spate.

Caddisfly species richness peaks earlier in the year than that of mayflies. In the relatively cool month of February, 17 species are active (Fig.3.12a), notably species of Hydropsychidae, Hydroptilidae and Leptoceridae.

(a)



(b)

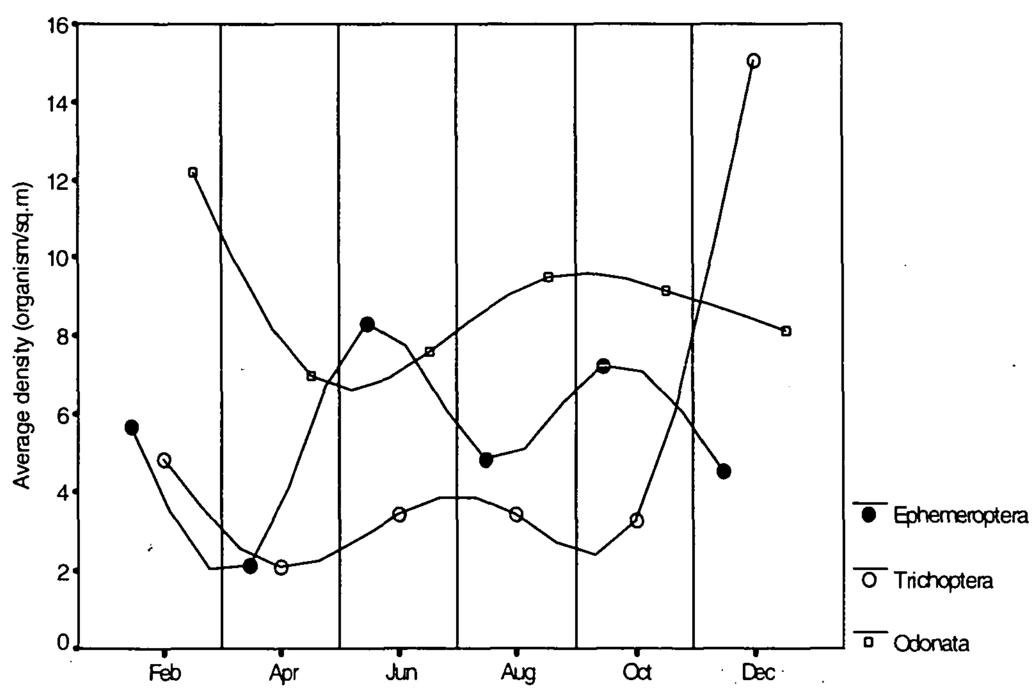


Figure 3.12 Bimonthly ephemeropteran , trichopteran and odonatan larvae assemblages (a) their species richness and (b) average individual density (Ephemeroptera x10^{-1}, Trichoptera x10^{-1})

The fragile case-caddis species (Hydroptilidae), in particular, are abundant especially in upstream sites, including *Hydroptila* sp., *Orthrotrichia* sp. and *Oxyethira* sp. Rare Leptoceridae species, *Leptocerus* sp. and *Triaenodes* sp. are also found during this month.

The net-spinning caddisfly species (Hydropsychidae) are also abundant in February: *Cheumatopsyche malaysiensis*, *Hydropsyche* sp., and *Leptonema* sp. and *Macrostemum similior*. The rarest caddis species in the Pong catchment is the psychomyiid *Tinodes* sp., with a single individual discovered in site P01 in February 1996.

The most widespread caddisflies in the catchment, which can be found in almost every month, are *Ecnomus* sp., *Polycentropus* sp. and *Phylocentropus* sp. All appear to dwell predominantly in rather deeper water in the lowlands, however all three species were absent from the severely polluted sites, P15 and P16.

Caddisfly larval densities peaked in December, averaging 150.7 organism/m^2, (Fig.3.12b). The most numerically dominant species during this month are *Cheumatopsyche malaysiensis* (averaging 2707.4 organism/m^2) and *Macrostemum similior* (averaging 209.9 organism/m^2). The first species is limited only to upstream sites, P01 to P03, while the second species is rather more widespread. *M. similior*, in particular, increased in numbers after the waterways recovered from severe flooding, in the same manner as the mayfly *Caenis* sp1.

Like ephemeropteran and trichopteran species, odonatan species richness reaches a peak in February, with a total of 21 species. For Odonata, the bimonthly variation of both species richness and density are synchronous (Figs. 3.12a and 3.12b). Similar to the seasonality seen in Trichoptera, species richness and density were reduced greatly in April (9 species), which is the hottest month. Density decreased from 12.5 to 6.9 organism/m^2 in the same period.

Gomphidae is the most diverse family of the dragonflies present in the catchment. *Erpetogomphus* sp. (31.5 organism/m^2) is the most abundant species and was represented in every bimonthly sampling, mostly in upstream sites. Gomphids, however, are rarely found downstream from site P15.

In August, odonatan species richness peaks at a total of 11 species, and average density rises to 37.3 organism/m^2. During this month, *Aphylla* sp. is the most prominent species with highest density of 29.6 organism/m^2. Unlike mayfly and caddisfly species, there is no evidence that any odonatan species are limited to a particular month of the year, probably because the immature stages are relatively long-lived. Therefore, Odonata communities tended to be site specific rather than determined by seasonality.

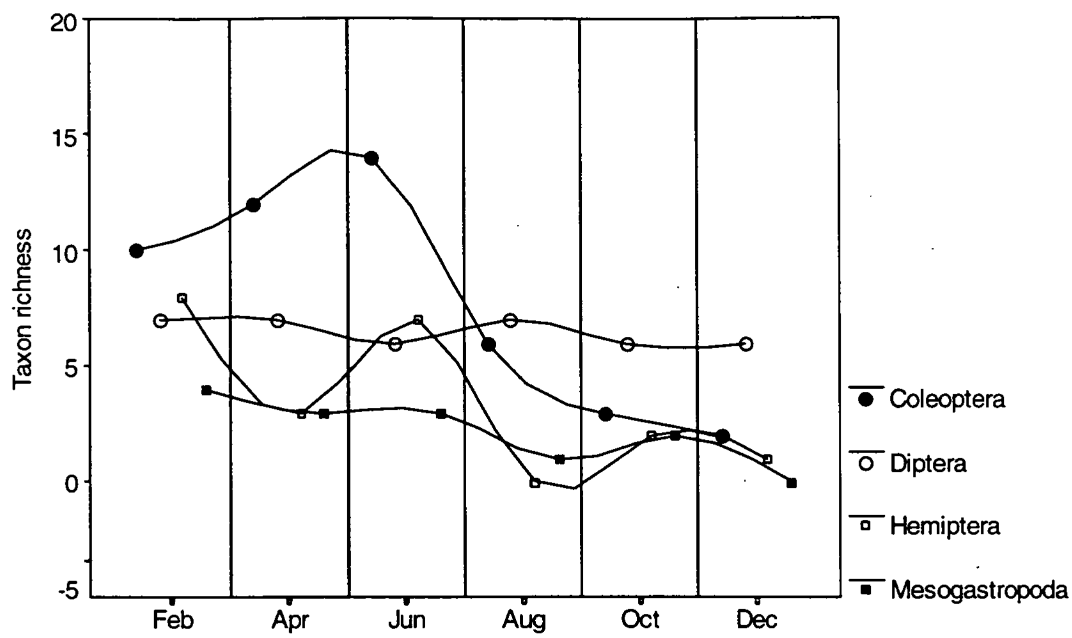
Unlike other taxa, water beetle species richness is at a peak in the mid-monsoon month of June, with a total of 14 species (Fig. 3.13a). The most abundant species in this month are the waterpenny scraper *Eubrianax* sp. (averaging 31.5 organism/m^2) and a gathering collector riffle beetle *Neocylloepus* sp. (averaging 57.4 organism/m^2). In this month, the most diverse species family is Elmidae. Most elmid species are largely restricted to the cooler waters of upstream sites. Among elmid species, abundance peak occurs at different times. For example, *Hexacylloepus* sp. peaks in April at 235.9 organism/m^2 while *Neocylloepus* reaches maximum density in February at 145.7 organism/m^2.

There is a marked reduction of water beetle species richness in October and December. In October, the most severely flooding month, only three species were found from all sampling sites: two elmids, *Hexacylloepus* sp., *Stenelmis* sp. and a chrysomelid *Donacia* sp. In December, only two water beetle species were recovered overall, a *Stenelmis* sp. and a water penny *Eubrianax* sp. Most water beetle larvae seem to be almost entirely displaced from the riverbed by the heavy scouring effect of floods rather than disappear for phenological reasons. This interpretation is supported by the presence of beetle larvae in ditches located across the rice field close to the Pong river at the end of the monsoon.

Like water beetles, water bugs are at highest density in June, averaging 17.9 organism/m^2. Species richness was high in two months, February (8 species) and June (7 species) (Fig.3.13a). Most water bug species in the Pong catchment belong to family Gerridae. These are *Cylindrostethus* sp., *Limnogonus* sp., *Rheumatogonus* sp., *Rhyacobates* sp. and *Trepobates* sp. Among these species, *Cylindrostethus* sp. has relatively the highest density in proportion to other water bug species, averaging 81.5 organism/m^2. Like water beetles, water bugs are confined to upstream sites and hardly found in lowland downstream locations (sites P13 onwards).

The distribution of hemipteran taxa was strongly influenced by the nature and extent of riverbank vegetation. Site P01, for example, located where there are few water edge grasses or shrubs, yielded no water bugs. Site P02 the site with maximum riparian grasses, in contrast, has maximum water bug species richness (see also Fig. 3.13a). In downstream waters, water bug is also absent in some sites, particularly from sites P13 onwards. As for water beetle larvae, hemipterans were rare at these lowland sites where the water current is relatively turbulent.

(a)



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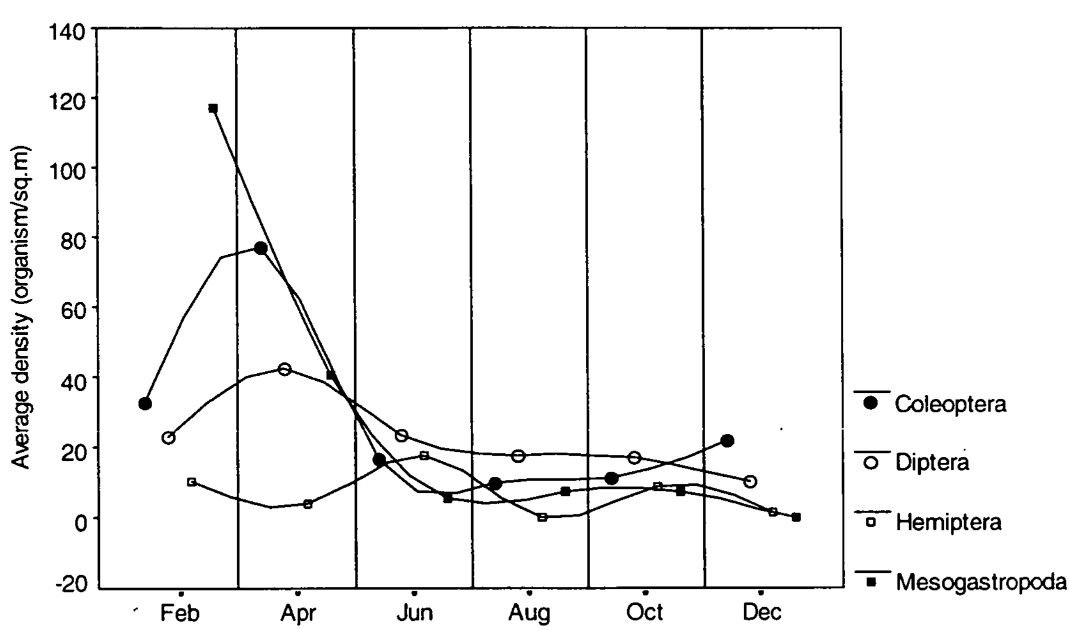


Figure 3.13 Bimonth coleopteran, hemipteran, mesogastropodan and dipteran larvae assemblages (a) species richness and (b) average density (Diptera density x10^{-1})

The numbers of water bugs caught in different times and places also fluctuated. In February, when the water current is less intense, water bugs were more abundant, whereas in October with severely stormy conditions, no water bugs were found at any sites. The availability of riverbank vegetation and water current therefore appear to be two critical factors which determine the occurrence of water bugs in the Pong catchment.

Unlike other benthic macroinvertebrate fauna, dipteran species richness was rather low but consistent and ranged from 6-7 species all year round (Fig.3.13a). Two dipteran taxa typically abundant all year round were the phantom midge *Chaoborus* sp. and non-biting midges Chironomidae spp. Average dipteran density peaks in the hottest month April, 425.9 organism/m^2 (Fig.3.13b). Its lowest density is in December, averaging 103.7 organism/m^2. *Chaoborus* sp. constituted maximal density in April, 1863.2 organism/m^2.

It is also recognised that when dipteran density peaks in April, average BOD level is also highest, while DO is relatively low (see also Fig.3.5b). Further, the average PO_4 and NO_3 levels measured in April are also high (see also Fig.3.6b).

Mesogastropod species richness peaks in February when 4 species were found (Fig.3.13a), whereas in December, no gastropod specimens were found during sampling. It appears that the gastropod scrapers are greatly abundant when the catchment waters return to normal state after heavy flooding. In the dry and cool month of February, the average gastropod density peaks with an average of 117.4 organism/m^2 (Fig.3.13b).

Most mesogastropod species sampled within the Pong catchment belong to the family Viviparidae. Abundant species are *Anulotaia* sp., *Filopaludina martensi*, *Mekongia* sp1 and *Mekongia* sp2. Most of these species are limited to upstream areas, particularly at sites P01 to P0, and were all abundant during sampling in February. *Mekongia* sp1 was the most abundant species, averaging 133.3 organism/m^2. The mesogastropods in this region are recognised as a major intermediate host for intestinal parasites.

Catchment-wide fauna variation analysed by multivariate methods

Ordination of the sites based on their average macroinvertebrate density over two years (Fig.3.14a) associated the sites in a manner which broadly agrees with the clustering produced by UPGMA. Both methods highlight sites P15 and P16, located in an urban area where they receive copious sewage discharged from Khon Kaen city. Very few benthic taxa exist in these two sites which have relatively high BOD levels indicated by the vectors (Fig.3.14c).

Many benthic species were associated with upper catchment sites (particularly sites P01 to P04) (Fig.3.14b). The waters of these sites feature relatively high alkalinity, velocity, and TSS levels, the latter two of which indicate that high rainfall and surface run-off markedly affect them. The most abundant taxa found within these sites are mainly Trichoptera, Plecoptera and Odonata.

There are some lower sites P11, P12 and P14 that were associated close to upstream sites based on their density of fauna. The first two sites are located well beyond the dam, while the last site is situated at a point before the Pong river enters the city.

Sites P06 to P08 on the lower Cheon river are well separated sites, grouped by UPGMA. These sites appear to have moderate benthic taxa abundance and waters with relatively high DO. Even though these sites are adjacent to extensive rice fields, they were notably rich in riparian vegetation which appears to influence their fauna strongly. The significant benthic taxa found at these sites are mainly deeper water caddisflies such as *Ecnomus* sp. and *Polycentropus* sp., and the beetles *Hexacylloepus* sp., *Cleptelmis* sp. and *Eubrianax* sp.

The last group comprised mixed sites arranged in the top left of the ordination space (Fig. 3.14a). The waters at these sites are variously impacted by damming, industrial and community discharges (Figs. 3.1 and 3.2) and typically have high rates of discharge and EC content. The benthic fauna that correlate with these sites are the mayfly *Litobrancha* sp. and the phantom midge *Chaoborus* sp. The first species is typically found in lowland sites with somewhat deeper waters, whereas *Chaoborus* is abundant in high EC content waters as at sites P19 to P20 where it is the dominant organism with an average density exceeding 1700 larvae/m^2.

It is noteworthy that there is an upper catchment site (P05) included in this last group. This site is located immediately above the large dam where it is impacted by the back-flow waters, and hosts large densities of the phantom midge *Chaoborus* sp. The waters of this site have high BOD and EC contents, particularly during the dry season, averaging 3.3 mg/L and 308.3 µS/cm, respectively. Organic and inorganic pollutants appear to have accumulated in this site. It is a buffer location, receiving waters from upstream discharge and downstream regulated waters from the

Ubolratana dam. Relative to other upper catchment sites, site P05 has the highest abundance of Chironomidae spp. and *Chaoborus* sp., which are 60.8 and 895.1 organism/m^2, respectively.

The ratio of *Chaoborus* sp. to Chironomidae spp. may be indicative of the heaviest organically polluted sites (e.g. sites P15 and P16). *Chaoborus* sp. density in these two sites are lower, 16.7 and 11.1 organisms/m^2 respectively, while Chironomidae spp. density are much greater with 438.5 and 310.4 organisms/m^2, respectively.

It appears here that even when *Chaoborus* sp. and Chironomidae spp. respond well to water pollution, each of them achieves relatively different densities in the presence of pollution. The abundance of *Chaoborus* sp. is significantly well related to high EC waters while the Chironomidae spp. correlates with BOD level. The high EC level originates from both natural and human induction while the BOD is mostly from community sewage.

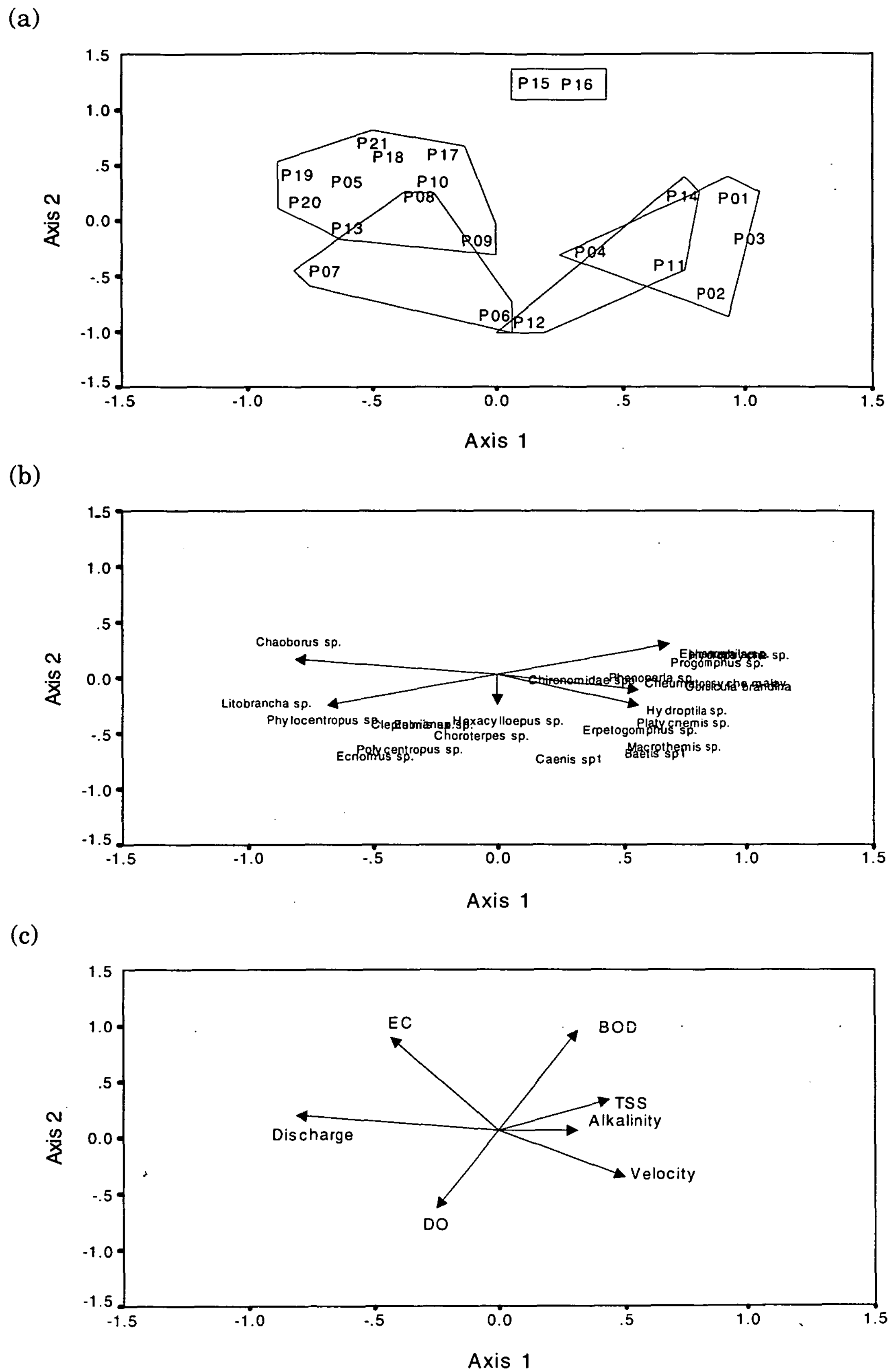


Figure 3.14 Biplots of (a) sites ordinated by HMDS (stress 0.1501), polygons and rectangular represent sites grouping by UPGMA, (b) significant species vectors (only species vectors with $r \geq 0.80$ are shown), and (c) environmental variables significantly correlate to the same ordination space

Initial summary associated with spatial and temporal benthic fauna distribution

At this stage, there are several conclusions regarding the benthic fauna distribution in the Pong catchment, which can be summarised as follows.

Spatial scale

(1) Spatial distribution of benthic fauna in the Pong catchment reflects aquatic ecosystem changes along the watercourse, but is modified by the impacts of land use which affect the local water condition. The upstream waters with less organic pollution have high species richness in their benthic larvae assemblages, while in the lowlands downstream, benthic species richness relatively declines.

(2) The upper catchment has greater species richness in the benthic fauna with lower individual density, while lowland areas have much higher densities of individuals but less species richness in the benthic communities.

Temporal scale

(3) The larvae of caddisfly, dragonfly and damselfly species peak in the latter months of the dry season prior to the onset of the monsoon when water flow is close to its minimum. Water beetles and water bugs species peak during the early wet season, while mayfly species richness peaks during the first rain. Unlike other taxa, dipteran species richness is relatively constant all year round.

(4) For each taxon group, the density of individuals markedly fluctuates between months. This is caused by a combination of factors including natural impacts and water degradation. The natural cause is mainly from surface-runoffs from land clearings that occurred mostly in upstream areas. In the lowlands, the waters become locally polluted from community sewage, industries and channel regulation by dams.

Section 3. Seasonal influences

Wet and dry season contrast

Benthic macroinvertebrate totalled 105 taxa in the dry season, but decreased to 88 taxa in the wet season. Average density also decreased from 133.1 specimens/m^2 in the dry period to 99.7 specimens/m^2 in the wet. It is noteworthy that most benthic larvae collected by this study in each sampling cycle were represented by mixed larval instars. This suggests that most taxa in the Pong catchment could have multivoltine life cycles. The scouring effect of seasonal flooding can therefore be inferred to be a major cause of local taxa reduction rather than life cycle phenology.

The data sets were divided into wet and dry seasons for further analysis. Ordination and clustering of each subset used average taxa density of individuals by HMDS and UPGMA. Outputs of seasonal data analyses are shown in Figs.3.15 and 3.16.

Interrelationships between taxa and aquatic environment: wet season

During the wet season, all of the upstream catchment sites (P01 to P04) are well separated from the remaining group sites (Fig. 3.15a). The most characteristic taxa which identify these sites are benthic species with claws, for example, elmids *Stenelmis* sp., *Cleptelmis* sp. and the tipulid *Limnophila* sp. (Fig.3.15b). The waters in these sites have relatively high velocity and TSS content during the wet season. Also, DO is remarkably high in these sites (Fig.3.15c).

Sites P11, P12 and P14 are grouped into another cluster by UPGMA (Fig.3.15a). These sites are dominated by caddis *Ecnomus* sp., *Phylocentropus* sp. and *Polycentropus* sp. These three species prefer to swim along edge waters, and existed where the waters are not very polluted as typical for these three sites (see also Fig.3.4b).

Sites P15 and P16 and a large group of other sites share high values of NO_3, PO_4, EC, TDS and water temperature in the wet season (Fig.3.15c). The most typical taxa here were the dipterans *Bezzia* sp., *Chaoborus* sp., Chironomidae spp., and Oligochaeta. Accordingly, this suggests that these animals are related to both nutrient and inorganic pollutants which are being discharged from both point and non-point sources in the wet season into this catchment.

Similar to the outcomes using average annual data (Fig.3.14a), the most organically polluted sites, P15 and P16, are still grouped together by UPGMA on the basis of the wet season data set (indicated as a single solid line in Fig.3.15a). During the wet season, organic pollutants as measured by BOD level are much reduced, but both sites still suffer from high nutrients (high NO_3, and PO_4 levels) and inorganic ions (high EC and TDS levels) (Fig.3.15c).

Regarding indicator taxa shown in Fig.3.15c, it is recognised that mayfly species are less significantly correlated to the ordination space. Only one species *Caenis* sp1 is found which highly correlates to the site ordination space (Fig.3.15b). It is therefore suggested that most mayfly taxa within this tropical floodplain suffer from high discharge. Benthic animals with claws can tolerate such heavy flows after storms much better such as those occurring in group sites P01 to P04 (Figs.3.15a and 3.15b). A few species which seem well adapted to swim in high level waters are the caddisfly species, *Phylocentropus* sp. and *Polycentropus* sp. which are abundant in sites P11, P12 and P14 (Figs.3.15a and 3.15b).

Other taxa which appeared to tolerate flooding are *Bezzia* sp., *Chaoborus* sp., Chironomidae spp. and Oligochaeta. These show significant correlation with the ordination space pointing to the high nutrients and inorganic ions impacted sites. In fact, *Bezzia* sp., Chironomidae spp. and Oligochaeta are true bottom sedentary dwellers on river bed. On the other hand, *Chaoborus* sp. has well developed leg-fans which enable it to swim in deeper waters.

Clear spatial discrimination between sites (Fig.3.15a) is apparent during the wet season. The water physicochemical direction vectors show the water quality pollutants' nature at each group site (Fig.3.15c). The significant benthic species are plotted as vectors towards each group site. Such species vectors also show reliable species specific ecological phenomena. These species well adapt to seasonal flooding (high velocity and TSS levels as discussed above. Also, in the case of dipteran Chironomidae spp. and *Chaoborus* sp. both species vectors correlate to human pollution source (high dissolved nutrient levels) (Fig.3.15b).

All sampling sites located over the catchment profile reveal different magnitudes of impact during the wet season. The upper catchment sites, P01 to P04, received much impact from surface run-offs (high TSS and velocity). Most downstream sites suffer from nutrient loading and dissolved inorganic salts, which are mainly accumulated and subsequently diffused from overland flows.

In general, the site groupings located in the ordination space using the wet season dataset appear to strongly reflect those obtained from applying the average annual benthic dataset (compare Figs.3.14a and 3.15a). However, the wet season dataset more clearly shows a separation of upstream group sites, P01 to P04, whereas in the average annual dataset, the organic polluted sites are more clearly discriminated.

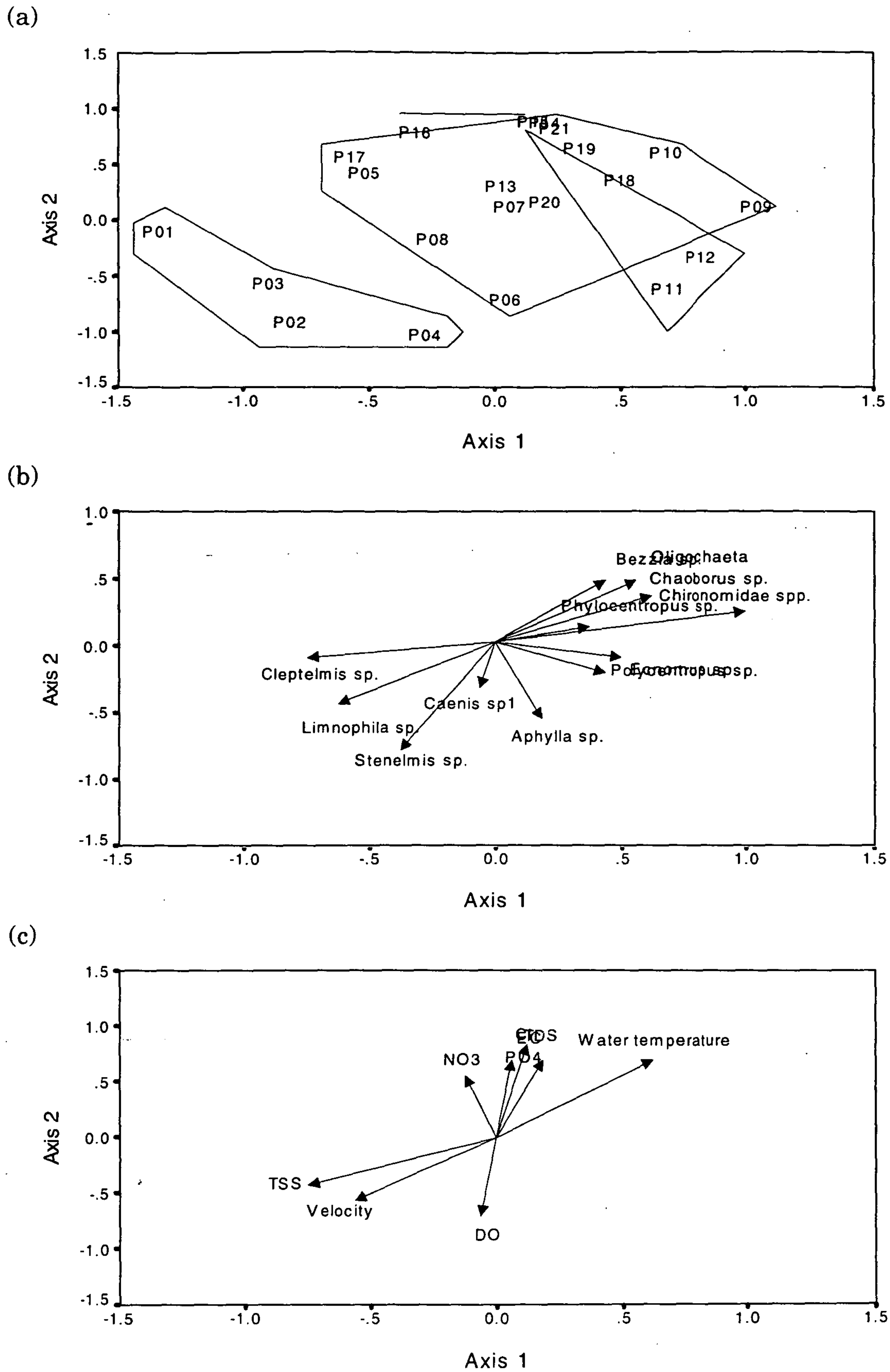


Figure 3.15 Biplots of wet season data (a) sites ordination by HMDS (stress 0.1687), polygons, triangle and line represent sites clustered by UPGMA, correspondingly, (b) and (c) species and physicochemical variables vectors significantly correlated with the same ordination space

There were more significant taxa relating to the ordination space in the average annual data set analysis than in wet season data (see comparatively Figs.3.14b and 3.15b). The existence of those taxa in average annual data is best related to landscape profile and pollution sources. For example, the species indicated in group sites P01 to P04 between annual and wet data sets analysis results are different (see comparatively Fig.3.14b and Fig.3.15b).

The annual data set mainly contributes indicator taxa for site groups which respond to the absence of organic pollution and/or are limited to these sites. The indicator species from the wet season data set analysis signify the intensity of flooding effect.

It is noteworthy here that the results from multivariate analysis (Figs.3.15a to 3.15c), suggest that any account of effects from water pollution on benthic taxa assemblages will be successful whenever one undertakes annual data analyses (Figs.3.14a to 3.14c).

Interrelationships between taxa and aquatic environment: dry season

Unlike the wet season, the sites ordination of dry season data by HMDS and clustering by UPGMA appeared to be comparatively well discriminated. Similar to the wet season, the upper catchment sites P01 to P04 are still grouped together, while the remaining sites are clearly divided into three main groups (Fig.3.16a).

During the dry season, the flow within the Pong catchment is mostly regulated by the dam and weirs in order to ensure that adequate water is supplied to the city and crop lands. Consequently, only sites P09 and P10 located below the dam have high discharge levels compared to other sites (Figs.3.16a and 3.16c). The upper sites P01 to P04 experienced occasional rain during the dry season, which was reflected in elevated levels of water velocity, turbidity and TSS (Fig.3.16c). Of the remaining sites, the waters are rather stagnant unless much water is discharged from the dam and weirs.

Similar to the wet season, benthic macroinvertebrate species are particularly abundant in sites P01 to P04. However, unlike the wet period when only certain elmid and tipulid species with claws and large appendages are dominant in these two sites (Fig.3.15b), in the dry season a mixed benthic assemblage is predominant in these sites (Fig.3.16b). Typical are the bivalve *Corbicula brandina*, the caddisfly *Macrostemum similior*, the water riffle beetle *Hexacylloepus* sp., the dragonfly *Macrothemis* sp. and the mayfly *Baetis* sp1.

Chaoborus sp. is another dominant taxon in the dry season which mostly occurs in the largest group sites (the topmost group of sites in Fig.3.16a). The upper site P05 is included in these grouped sites.

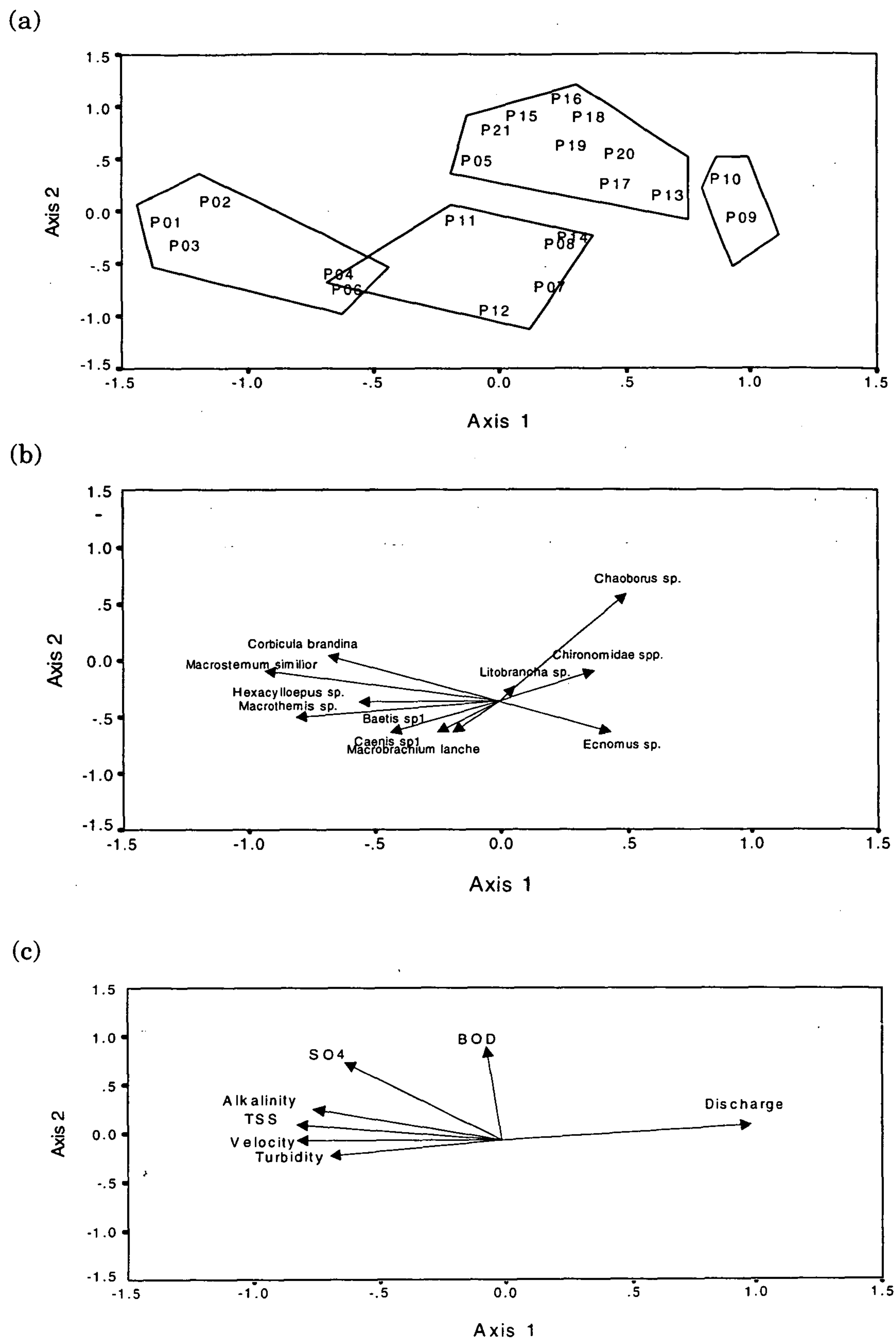


Figure 3.16 Biplots of dry season data (a) sites ordination by HMDS (stress 0.1172), polygons represent sites clustered by UPGMA, correspondingly, (b) and (c) species and physicochemical variable vectors significantly correlated with the same ordination space

During the dry season, these sites are severely impacted by organic pollution as revealed by the high BOD level (Fig.3.16c). Thus, there are not many benthic taxa found in these sites in the dry season. Accordingly, there was no significant benthic species produced by the ordination vectors towards these grouped sites (Fig.3.16b). Only *Chaoborus* sp. was correlated to sites P19 and P20, the sites with high EC levels.

Chironomidae spp. was a dominant taxon which occurred abundantly at sites P09 and P10, during the dry season, and seems to be attributed to two main factors. Firstly, it appears that the organic sediments (including nutrients bound in anaerobic conditions) discharged from the dam are accumulated around this area during the dry season (via occasionally regulating water supply to downstream by the dam), and therefore midge larvae flourish at these sites. Secondly, the residue deposit in the river bed, mainly lignin and tannin discharged from the large pulp mills factory is located in this area. A combination of these two factors may therefore have stimulated high abundances of chironomid midges.

Sites P06 to P08, P11 to P12 and P14 are associated by UPGMA. The waters measured in these sites show no clear evidence of impact and these sites show better recovery from the previous flooding period. Common benthic larvae found are *Caenis* sp1, *Ecnomus* sp. and *Litobrancha* sp.. A few species such as *Caenis* sp1, begin to dominate the benthic community (Fig.3.16b).

In the dry season, the organic pollutant BOD was highly correlated to the ordination space, and as it was for the average annual data set (see Figs.3.14c and Fig.3.16c). Its direction points to the largest group sites (the topmost group in Fig.3.16a). Within this group, the extreme BOD levels occurred in sites P15 and P16 during the dry season, averaging 13.1 and 15.2 mg/L, respectively. Thus, BOD level becomes the most significant water quality variable in relation to impacted sites during the dry season.

TSS, velocity, SO_4, alkalinity, and turbidity all correlated well to group sites P01 to P04 (Fig.3.16c). These grouped sites nevertheless had some occasional rains during the dry season, which occured rarely at downstream sites. Thus, water velocity, TSS and turbidity proved to be significant correlated variables. When it is not raining, dissolved salts are easily detected in these sites during summer, as indicated by SO4 and carbonate alkalinity.

When comparing wet and dry seasons, it appears that nutrient levels, NO_3 and PO_4, are major pollutants occurring only in the wet season (compare Figs.3.15c and 3.16c). This suggests that such high nutrient levels in the wet season are from diffuse run-off rather than from mineralising nutrients from the river bed which might be resuspended to the water column.

Initial summary associated with seasonal influence

There are several key points involving the influence of seasonality on the benthic fauna within the Pong catchment, summarised as followings.

Seasonal confounding effects

(1) Seasonal flooding causes a marked reduction of the benthic fauna in both taxa richness and density. In dry and cool months benthic fauna are more abundant, and decline following heavy storms during the mid-late rainy period.

Wet season specific

(2) Species specific responses are apparent in the wet season. Larvae with claws, mostly riffle beetle species, can better tolerate severe flooding and are found predominantly in upstream areas. Oligochaeta and Diptera such as the non-biting midge Chironomidae spp. and phantom midge *Chaoborus* sp., are very abundant in lowland waters.

(3) Discrimination of catchment sites by multivariate methods (HMDS and UPGMA) is poor during the wet season. The only result which can be seen clearly is the uppermost upstream sites which suffered from high spate, being separated from the lowland waters sites. The latter grouped sites are effected by upstream spate (see also Fig.3.15a).

(4) Apart from high discharge, prominent water quality impacts during the wet season are from highly diffused nutrients and suspended solids (TSS) from surrounding lands. All these further affect the distribution of benthic taxa at a site.

Dry season specific

(5) Benthic taxa become rich in upstream sites whereas they decrease in the lowlands. Several sensitive species begin to colonise which are limited to upstream sites.

(6) All sites based on benthic individual data within the catchment can be clearly separated by multivariate analyses with fine-scale discrimination among grouped sites. Such grouped sites are well related to both fauna and water pollution.

(7) Organic pollution, particularly BOD, becomes more apparent especially downstream. Human impact on aquatic ecosystems reduces benthic species but increases the number of specimens of tolerant taxa.

Section 4. The fate of the transition zone

Location of the transition zone

A special investigation was made of the fate of waters and benthic species in a transition zone along the Pong river where water quality appears to be considerably naturally improved in an apparent "self purification zone". Certain sampling stations showed this phenomenon, particularly the river reaches before the waters flow across Khon Kaen city (see Figs.3.1, 3.2 and 3.4b), in particular, between sites P11 to P13.

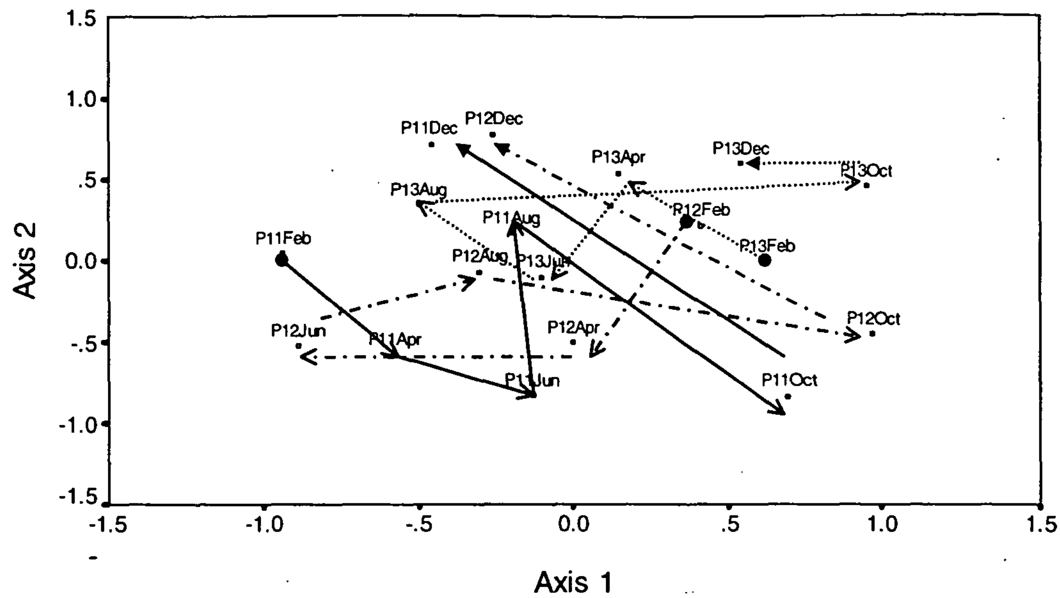
Site P11 is located above discharge points from a cassava processing factory, piggery farms and large agricultural land run-offs. Even though this site is situated below the distillery and sugar mills, these two large industries now practise zero discharge. Site P12 and its upstream reach received effluent from a large cassava processing plant and piggery farms (Fig.3.2). Further downstream at site P13, the Pong water was impacted by mostly surface run-offs from vast rice and vegetable plantation fields. The rice and vegetables in this area are grown all year round as irrigation waters are supplied via the Nong whai weir.

Site P11 has a comparatively high average DO level when compared to other downstream sites (Fig.3.4b). In relation to the point and non-point discharge phenomena related to these sites, there may be differences between the corresponding benthic species and their community assemblage between the sites. Thus, multivariate analyses focus on the benthic community variation between these sites.

Temporal translocation between transition zones

Figure 3.17a shows translocation of all three sites across the ordination space using average bimonthly benthic taxa density from February till December. The most distinct feature is that these sites have different species numbers and densities varied by bimonthly intervals. The waters in site P11 in February are cleaner, having high DO content and low BOD levels. This site has the most diverse benthic taxa abundance, while sites P12 and P13 had relatively more impacted waters with lower benthic taxa abundance. These latter sites, as shown in Fig.3.17a, had their origins in the ordination space proximate to each other but distant from the origin of site P11.

(a)



(b)

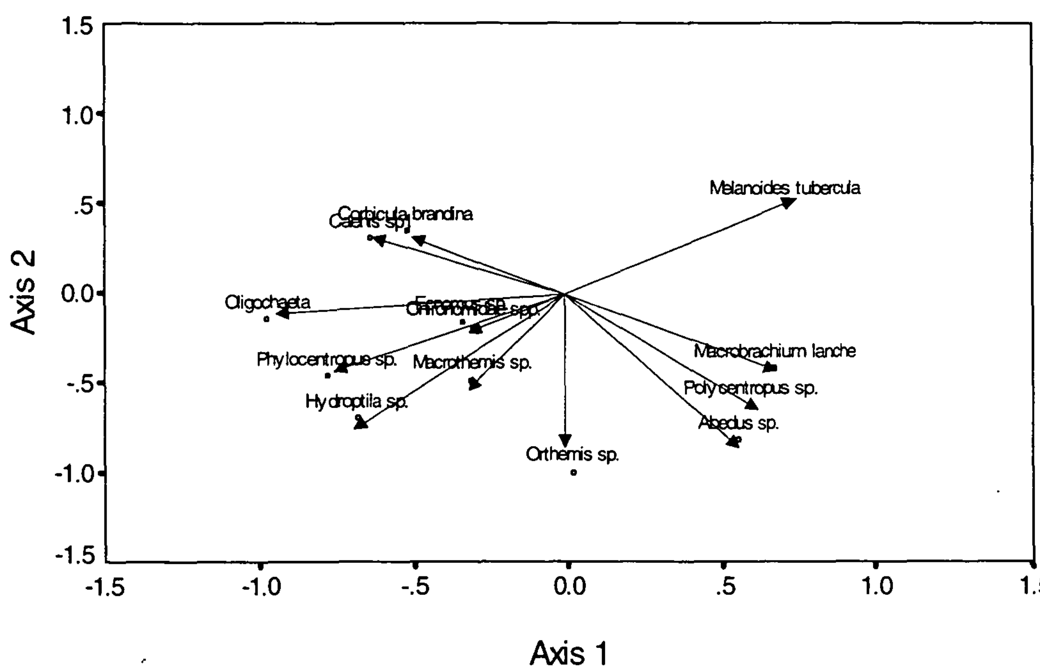


Figure 3.17 Biplots between axis 1 and axis 2 of (a) HMDS ordination results of benthic density of sites P11 to P13 (stress 0.1758) and (b) vectors of benthic species significantly correlated with the ordination space.

All three sites were clearly impacted by high discharge that started in August (Fig.3.17a). Also, in October, all sites suffered severely from heavy flow within the river channel. Later in December, benthic community in sites P11 and P12 were likely to recover from seasonal heavy flooding. Site P13, however, received more impact from additional extensive run-offs from agricultural lands and benthic community appears to return to normal state to a lesser extent than those two upstream sites.

There are some benthic species that significantly correlate with site ordination. In August, when the water channel began to fluctuate markedly, caddis *Ecnomus* sp., Chironomidae spp. midge larvae and bivalve *Corbicula brandina* were the most common species found in all sites. During heaviest flooding in October, indicator species were the water bug *Abedus* sp., the caddisfly *Polycentropus* sp., the freshwater shrimp *Macrobrachium lanchestri* and the gastropod *Malanoides tuberculata.*

During the transition period from April, the hottest dry month, to early rainy month June (the first rain), the most common benthic species were the caddisflies *Phylocentropus* sp., and *Hydroptila* sp., the dragonfly *Macrothemis* sp. and Oligochaeta.

There is one benthic taxon which shows a remarkable abundance before and after raining periods, the mayfly *Caenis* sp1. It is abundant in sites P11 and P12, but with very limited numbers in site P13 (7.0 specimens/m^2) even in the low-flow period. The appearance and reappearance of this species in downstream lowland reaches seemed closely related to aquatic environmental stress, both from human and natural perturbations.

Key findings from the ordination analysis:

• Although these three sites were located within the same river reach, their benthic community changes with time in different directions. The origins of the impact sites (P12 and P13) are proximate but distant from the less impact site (P11) (although February data forms the origin, any month could be used without changing the results). It is clear that site P11, with relatively cleaner water, has a characteristic benthic community with a different origin from the impacted sites in the ordination space (Fig.3.4b).

• All sites changed their positions in different ways in the ordination space from their origins, but all are directed in the same direction when entering the heavy flooding period in October.

• In December, when the climate becomes cool and dry with minimal flooding effect, the benthic community at all sites recolonise in the same direction (see Dec in Fig.3.17a). However, the recolonising magnitude of all sites is variable. Highly impacted sites (P13) appeared to recover more slowly than the other two sites (P11 and P12).

The less polluted (P11) and moderately polluted (P12) sites has similar recovery direction (see P11Dec and P12 Dec in Fig.3.17a). But the more polluted site (P13) has relatively slow recovery.

• Although site P12 was relatively more impacted than P11 (as clearly seen by their different origins), eventually in December they will have the same fate. The overall results suggested that to assess water quality impact via using benthic macroinvertebrate fauna, it should conducted during dry months which had more reliable results than in rainy months. This is because, irrespective of the magnitude of impacts, the fauna will face the same fate during rainy months due to heavy spate in all sites.

• A useful indicator species may be the presence of mayfly *Caenis* sp1. While this species is often found to appear immediately before and after flooding periods in relatively less polluted sites (P11 and P12), this species was hardly found downstream at site P13 in the same watercourse. This suggests that site P13 is possibly not a habitat suitable for larval development of *Caenis* sp1, even though this site has exactly the same physical features, but different water quality.

Section 5. Spatiotemporal variation of each taxon

The benthic macroinvertebrate community as a whole, has a particular distribution pattern which varies with time and space, and which also relates to certain environmental stresses.

The distribution of each benthic taxon (per order) will be analysed within the Pong catchment. This may yield relationships between the distribution pattern of each taxon and prevailing environmental conditions.

Water beetles

Water beetle species richness differed markedly between upper and lower catchment sites (Appendix 2.1). The upper sites (P01-P08) collectively had 20 species while the middle and lower sites had a total of 10 and 7 species, respectively. No water beetles were found at sites P09 and P10 located below the Ubolratana dam and sites P15 and P18 in the city area.

Riffle beetles (Elmidae) were the most diverse family with 9 species in the Pong catchment: *Ancyronyx* sp., *Cleptelmis* sp., *Dubiraphia* sp., *Hexacylloepus* sp., *Macronychus* sp., *Neocylloepus* sp., *Neonelmis* sp., *Ordobrevia* sp. and *Stenelmis* sp. Of these, *Hexacylloepus* sp. and *Neocylloepus* sp. were the numerically dominant taxa in the upper catchment, especially during the dry season when they clung to submerged stones in large numbers. However, both were not uniformly widespread in all upstream sites but rather restricted to certain sites in rather cool and less polluted waters. *Hexacylloepus* sp. was more abundant in site P06 (mean individual density, 1014.8 specimens/m^2) while *Neocylloepus* sp. was dominant in site P01 (mean individual density, 237.0 specimens/m^2).

Water beetle species were often favoured by dense riparian habitat. Site P06, for example, with its abundant streamside vegetation had the highest species richness (n=11 species) and the greatest individual density of individuals (99.3 specimens/m^2).

Of 25 water beetle species, the most common species within the whole catchment were *Stenopelmis* sp., *Cleptelmis* sp. and *Stenelmis* sp.

Area specific species were: the water penny *Eubrianax* sp., the carabid *Chaenis* sp., predaceous diving beetles *Dytiscus* sp. and *Agabus* sp.; and the elmid beetles; *Ancyronyx* sp., *Macronychus* sp., and *Neonelmis* sp. All these species were limited to the upper catchment sites.

The rice pest *Tanysphyrus* sp., diving beetle *Hydaticus* sp. and scavenger *Hydrophilus* sp., on the other hand, were abundant in the lower catchment sites.

Five beetle species were highly correlated to the site ordination space based on beetle species densities: the rice root shredder weevil *Stenopelmis* sp. (r=0.89), the diving piercer *Hydaticus* sp. (r=0.83), the whirligig beetle *Dineutus* sp. (r=0.76) and two riffle elmids *Hexacylloepus* sp. (r=0.76), and *Neocylloepus* sp. (r=0.77). The first two species were abundant in lowland waters while the last three species were common in the upper sites (Fig.3.18).

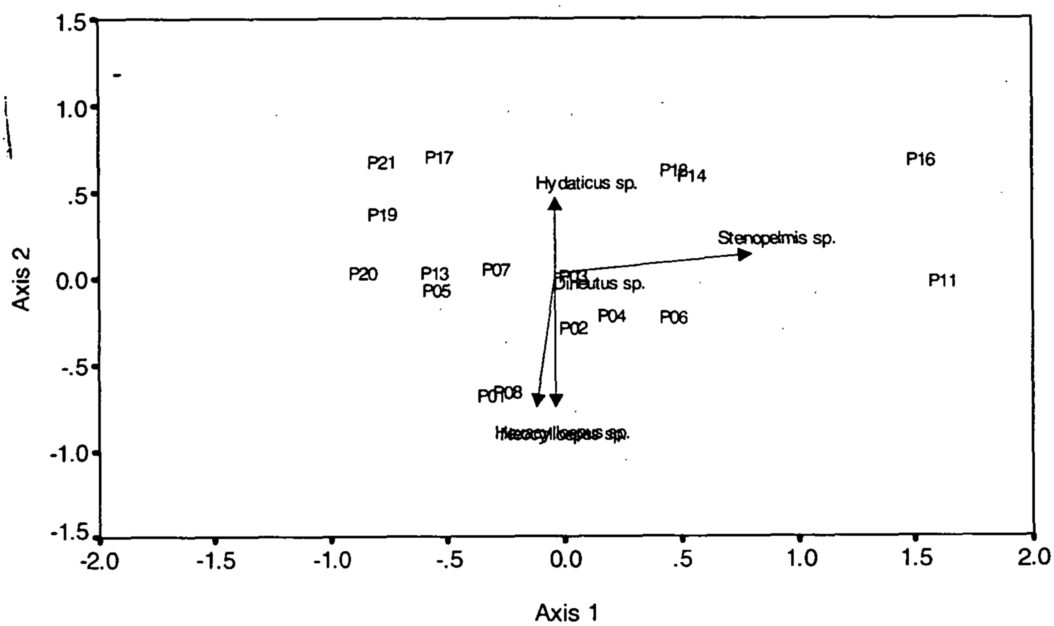


Figure 3.18 Sites ordination using water beetle individual density by HMDS, and species vectors significantly correlated with the ordination space (stress 0.1031)

True flies: Diptera

The distribution of the dipteran fauna varied markedly according to the catchment gradient and the season. The upper sites had lower individual density (90.9 specimens/m^2) than the middle and the lower catchment sites, which were 374.6 and 530.2 specimens/m^2, respectively. Two taxa, Chironomidae spp. (49.3%) and *Chaoborus* sp. (45.7%), constituted almost all of the 18,543 dipteran specimens recovered from the two-year study, and the density of larval Diptera was almost three times higher in the dry season than in the wet season (481.5 and 174.8 specimens/m^2, respectively).

The distribution of Diptera species generally related to catchment profile. Species significantly correlated to the disposition of sites in the ordination space were, for upstream sites: *Atherix* sp., *Atrichops* sp. *Hexatoma* sp. and *Simulium* sp., and for downstream sites were *Chaoborus* sp., Chironomidae spp. and *Culicoides* sp. (Fig.3.19).

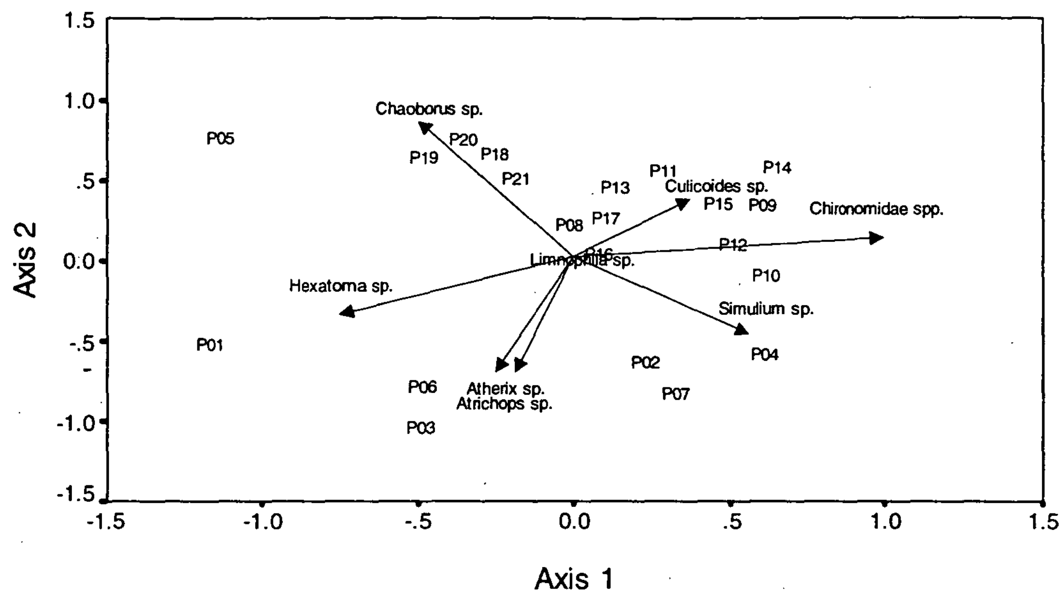


Figure 3.19 Sites ordination using dipteran species by HMDS (stress 0.094), vectors indicating dipteran species significantly correlated with the ordination space

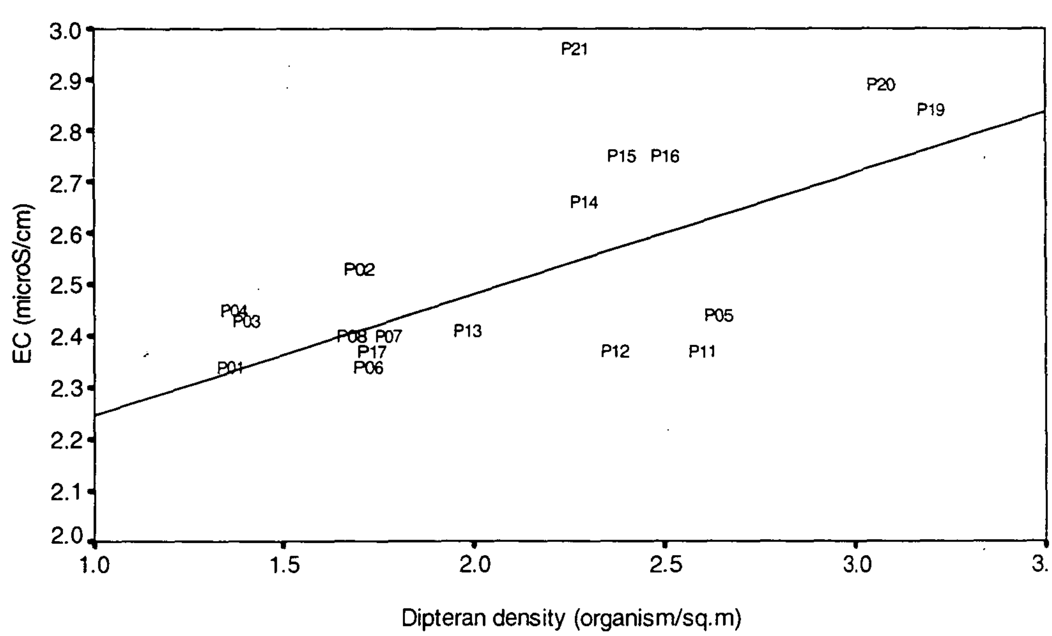


Figure 3.20 Biplot between dipteran individual density (log x+1) and EC (log x), solid line represents linear regression fit line

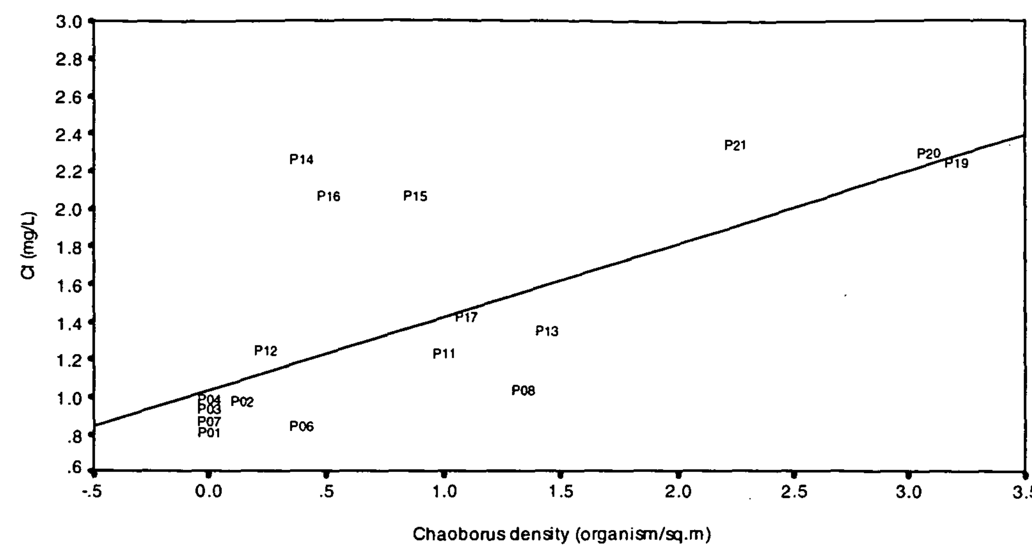
Chironomidae spp. and *Chaoborus* sp. were extremely abundant in waters with a high EC level caused by city sewage and salt rock intrusion.

Figure 3.20 shows a high relationship between individual dipteran density and EC level by regression analysis (r^2=0.41, $F_{1,16}$=11.00, P<0.01).

The high EC caused by substratum rock salt was apparent in the lowermost part of the catchment, sites P19 to P21. In these sites, *Chaoborus* sp. was the most dominant benthic species. *Chaoborus* sp. is also associated with chloride-rich waters where it is tolerant of high Cl levels (Figure 3.21a, linear regression, r^2=0.46, $F_{1,15}$=12.92, P<0.01).

Chironomidae spp. were abundant in the sites (P15 and P16) which received city or community sewage and consequently had very high BOD values. Figure 3.21b shows a marked relationship between average Chironomidae spp. individual density and BOD level (r^2=0.51, $F_{1,13}$=13.577, P<0.01). Sites P15 and P16, particularly during the dry season, had the highest average BOD levels, 13.1 and 15.2 mg/L, respectively. Both also had highest average Chironomidae spp. individual, averaging 478.5 and 602.2 specimens/m^2, respectively.

(a)



(b)

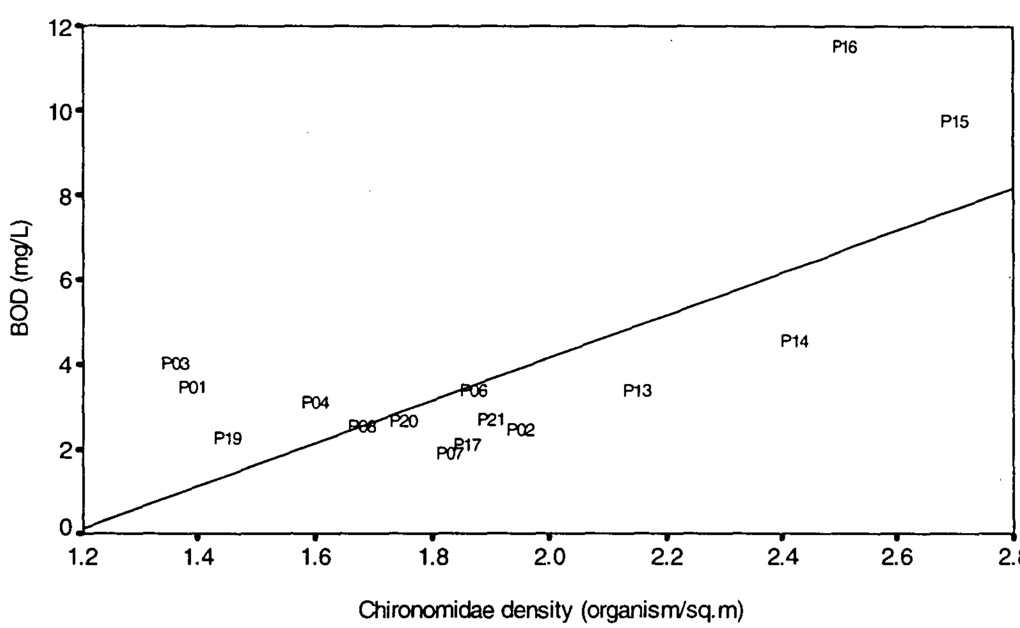


Figure 3.21 Biplots (a) between average *Chaoborus* sp. density (log x+1) and chloride ion (log x) and (b) BOD level and average Chironomidae spp. density (log x+1), all solid lines represent regression fit lines

Dragonflies and damselflies

Twenty five species of Odonata were recorded in the Pong catchment and their abundance varied according to location in the catchment. Species richness of odonatans was highest in the upper sites (n=20 species), while the middle and lower catchment had 16 and 5 species, respectively.

On a total catchment scale, both dragonfly and damselfly nymphs had almost the same density: 9.0 and 9.6 specimens/m^2, respectively. Coenagrionidae, Gomphidae and Libellulidae were the most widespread Odonata familis and only the family Aeshnidae was limited to the upper catchment waters.

The Gomphidae (n=9 species) was the most diverse family in terms of species represented in the catchment. *Sinogomphus* sp. and *Hagenius* sp. were widespread, whereas *Dromogomphus* sp., *Progomphus* sp. and *Seiboldius* sp. were restricted to upper sites.
Dragonflies which significantly correlated with the ordination of the sites based on this order were all Gomphidae (Fig. 3.22). *Aphylla* sp. is the only species which significantly correlates with the upper sites (r=0.78, P<0.05); *Stylurus* sp. (r=0.75, P<0.05) correlates with the middle catchment sites and two species, *Hagenius* sp. (r=0.71, P<0.05) and *Sinogomphus* sp. (r=0.75, P<0.05), are strongly associated with lowland sites.

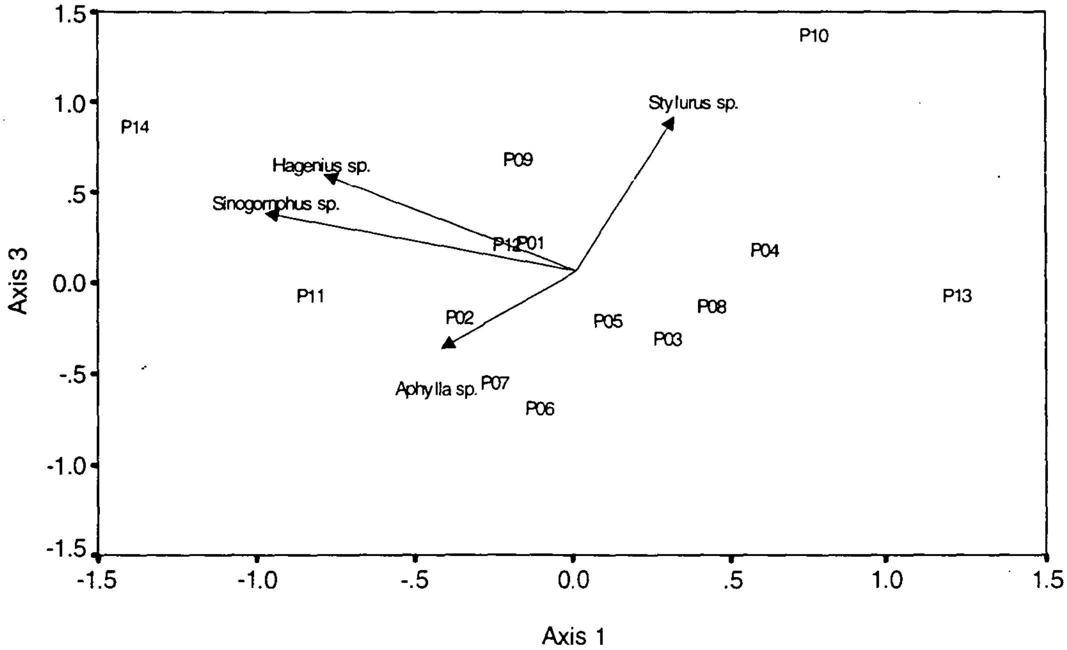


Figure 3.22 Biplot between axis 1 and axis 3 from sites ordination by HMDS (stress 0.1512) using Odonata density data

Water bugs

Nineteen species of water bugs were discovered in this study of the Pong river system. They were more abundant in upstream sites than in downstream impacted sites, and none occurred in lowland waters between sites P13 to P21.

Gerridae was the dominant family with 5 species, of which *Rheumatogonus* sp. was the most widespread and common species with an average density of 51.9 specimen/m^2. However, water bug abundance varied seasonally. Most Belostomatidae, Nepidae, Notonectidae and Corixidae were more abundant in the dry season, whereas Hebridae and Mesoveliidae were dominant during the wet season.

Four bug species were significantly correlated with an ordination of the sites based on the abundance and identity of their hemipteran fauna (Fig. 3.23). *Mesovelia* sp1 is more abundant in upper catchment sites (r=0.79, P<0.05) while *Tenagobia* sp. (r=0.90, P<0.01), *Cylindrostethus* sp. (r=0.79, P<0.05), and *Micronecta* sp. (r=0.78, P<0.05) exist in both upstream and downstream waters.

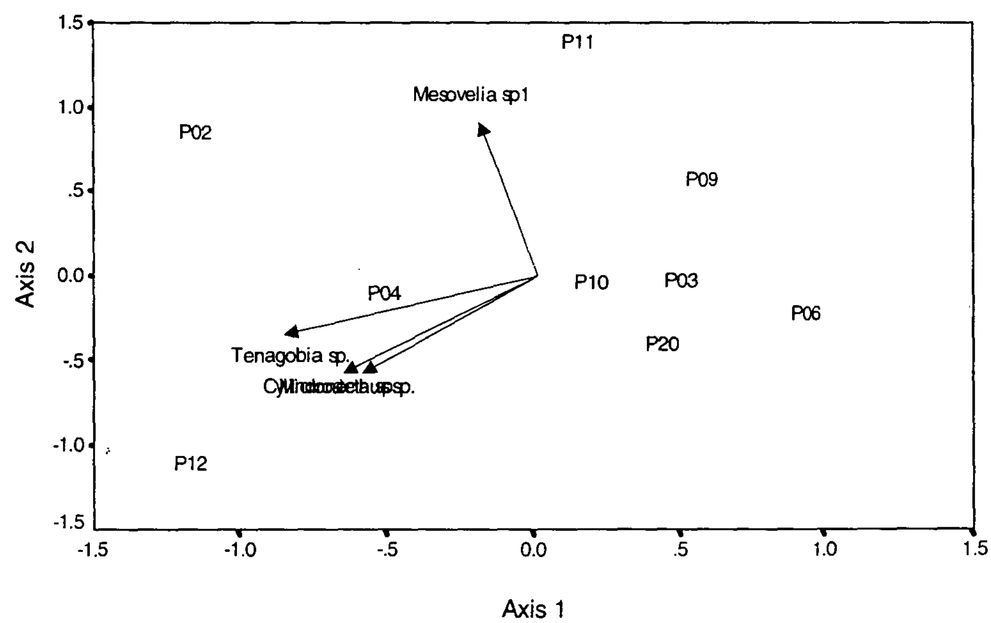


Figure 3.23 Sites ordination by HMDS (stress 0.1802) using hemipteran individual density data, vectors indicating species significantly correlated to the ordination space

It is noteworthy that, on the basis of hemipteran individual density data, the sampling sites are rather scattered over the ordination space and do not form discrete clusters (Fig. 3.23). Also, there is no obvious spatial arrangement of the sampling sites that readily relates to water quality or any other environmental gradient (e.g. landscape profile). Thus, to relate the distribution of hemipteran to other environmental factors, including water pollution, is not possible in this instance. However, similar to other invertebrate groups, Hemiptera was never found in downstream impacted sites.

Many of the sampled Hemiptera were technically semiaquatic insects, and their patterns of distribution were also determined by factors such as riparian vegetation rather than solely depending on water quality. Consequently, the hemipteran fauna distribution is of limited use when accounting for episodes of water pollution.

Mayflies

A total of 18 species and 2240 specimens of mayfly larvae were recovered from the riverbeds of the Pong catchment. The upstream sites have markedly higher species richness than the middle and downstream sites. The organically impacted sites P15 and P16 yield no mayfly species during the two years of sampling.

The sites located immediately above and below Ubolratana dam have relatively low mayfly species richness. For example, site P15, P09, P10 and P17 have comparatively low mayfly species assemblages, Fig. 3.24. Upper catchment sites in contrast have higher mayfly species numbers that ranges from 7-11 species. However, one site downstream P14 had high mayfly species richness and the waters appear to recover to a normal state after being polluted by mixed community and industrial effluent (see also Fig. 3.2). Further downstream well beyond this site, i. e. sites P15 and P16, the waters are re-polluted.

Sites P01 to P04 and P06 in the upper catchment had a highly diverse mayfly fauna (having less density but high species number), Fig. 3.24. The sites located adjacent to rice fields (P07 and P08), and the sites below the dam (P09 and P10), have high mayflies density but lower species abundance, and are dominated by *Litobrancha* sp., *Campsurus* sp. and *Caenis* sp1. The first two species are mostly found in rather deep-water reaches, whereas *Caenis* was widespread throughout the catchment except where waters were very polluted.

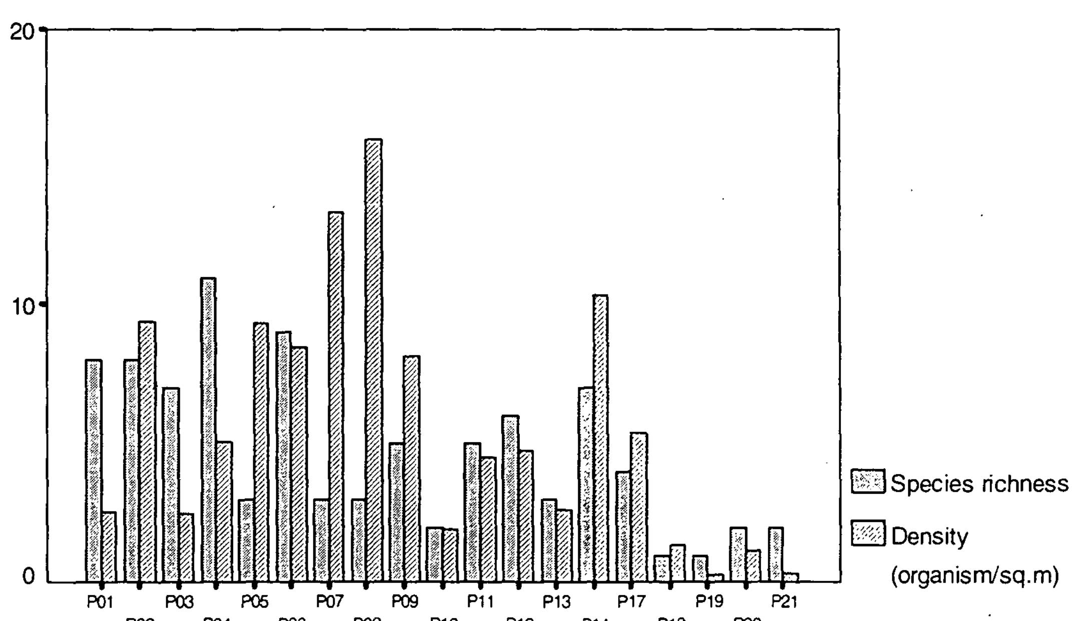


Figure 3.24 Spatial mayfly species richness and its density in all sampling sites

The families Heptageniidae and Leptophlebiidae were largely restricted to upper catchment sites, particularly P01 to P04 and P06, which less polluted by organic and industrial wastes (Fig.3.2). The species mostly limited to these sites were the heptageniids; *Heptagenia* sp. and *Arthroplea* sp., and the leptophlebiids, *Choroterpes* sp., *Habrophlebiodes* sp., *Leptophlebia* sp., *Paraleptophlebia* sp. and *Traverella* sp. These species are normally classified as sensitive taxa. In contrast, *Baetis* sp1, *Baetis* sp2, *Caenis* sp1 and *Caenis* sp2 were rather widespread and can be found almost everywhere, except in some grossly polluted sites such as P15 and P16. *Litobrancha* sp., and *Potamanthus* sp. were species with rather a widespread distribution but were located mostly in lowland waters.

The ordination of the site based on mayfly data confirmed the site groupings identified by UPGMA (Fig.3.25).

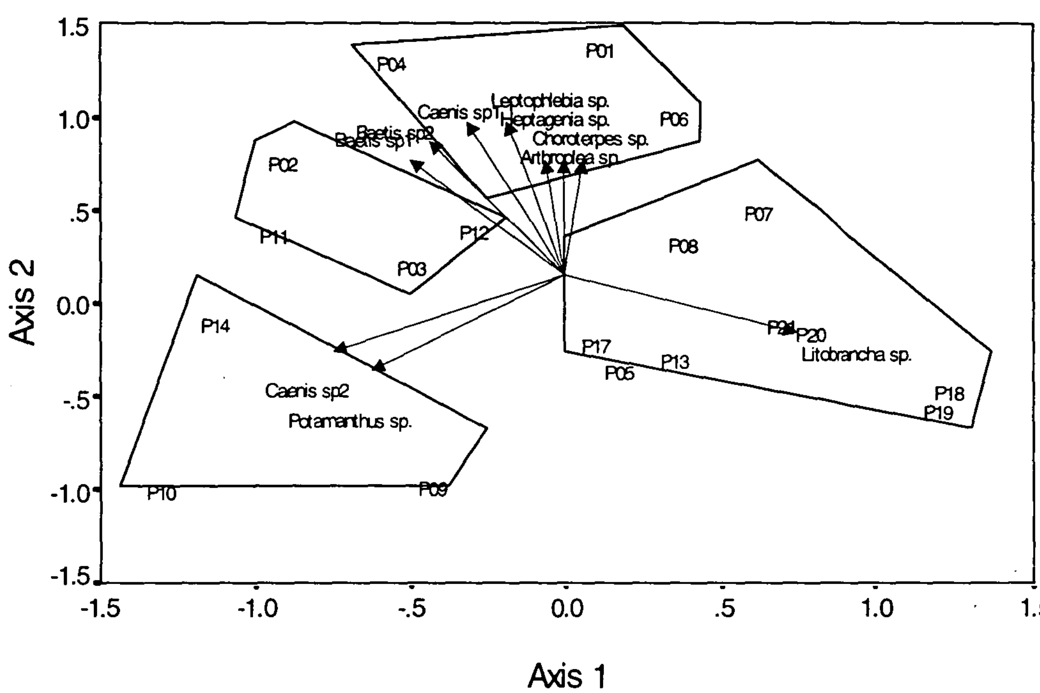


Figure 3.25 Sites ordination by HMDS (stress 0.1315) using mayfly density data transformed by log (x+1). Vectors indicate species significantly correlated to the ordination space and polygons represent sites grouped by UPGMA

Figure 3.25 also shows that the upper catchment sites have high diversity of sensitive mayfly species. There are two lowland sites, P11 and P12, which are grouped with upstream sites.

A correlation analysis between UPGMA site groups and environmental variables by using DFA, reveals that only Function1 is significant when

tested by Wilks' Lambda. The DFA when using environmental variables alone can classify the UPMGA site groupings with 100% prediction.
The pooled within-groups correlations between discriminating variables and canonical discriminant functions are shown in detail in Table 3.2.

The most significant environmental variables that best correlate with the UPGMA site groupings are depth, DO, and water velocity. In other words, these three environmental variables condition the abundance of mayfly species at a site. The upstream grouped sites (P01, P04 and P06) with much more diverse mayfly species, have relatively high DO level, high water velocity and shallow waters when compared to other UPGMA site groups.

Table 3.2 Pooled within-groups correlations between discriminating environmental variables and canonical discriminant functions for UPGMA site groups based on mayfly abundance data

(Functions 1 and 2, P=0.0069 and P=0.1560 respectively when tested by Wilks' Lambda, 100% prediction UPGMA group memberships)

Environmental variable	Function 1	Function 2
ALTITUDE	0.09974	-0.01037
RAIN	0.09070	0.04881
LOGCL	-0.07105	0.02205
LOGTDS	-0.04313	0.04288
WATERTEMP	0.01111	-0.40878
LOGTUR	0.03389	0.17515
LOGEC	-0.0436	0.06787
PO4	0.01866	0.04281
NO3	0.03471	0.05127
DEPTH	-0.12634	-0.04717
DO	0.12342	0.16215
VELOCITY	0.15864	-0.02338
LOGTSS	0.05656	0.13211
LOGALKA	0.07093	0.02853
BOD	0.01365	-0.05981
LOGDISCHARGE	-0.08171	0.06497
Canonical correlation	**0.9929**	**0.9734**
Percent variance explained	**77.30**	**20.01**

Another UPGMA group sites are P02, P03, P11 and P12 in which the first two are of upstream area while the second grouped sites are located in middle catchment reach. Even sites P11 and P12 have relatively higher discharge but their waters are rather shallow with high DO levels. These two sites have been discovered to have more diverse mayfly species. Site

P14 even when its water column is shallow has relatively low DO and mayfly species is rarely found.

In summary, the occurrence of mayfly species within the Pong catchment is most dependent upon a combination of factors of DO, water depth and velocity.

Caddisflies

The community of caddisfly species varies in a similar way to the mayfly taxa. Less disturbed upstream sites had relatively higher species numbers of both taxa while lowland downstream impacted sites have minimal mayfly and caddisfly species richness (Fig.3.26).

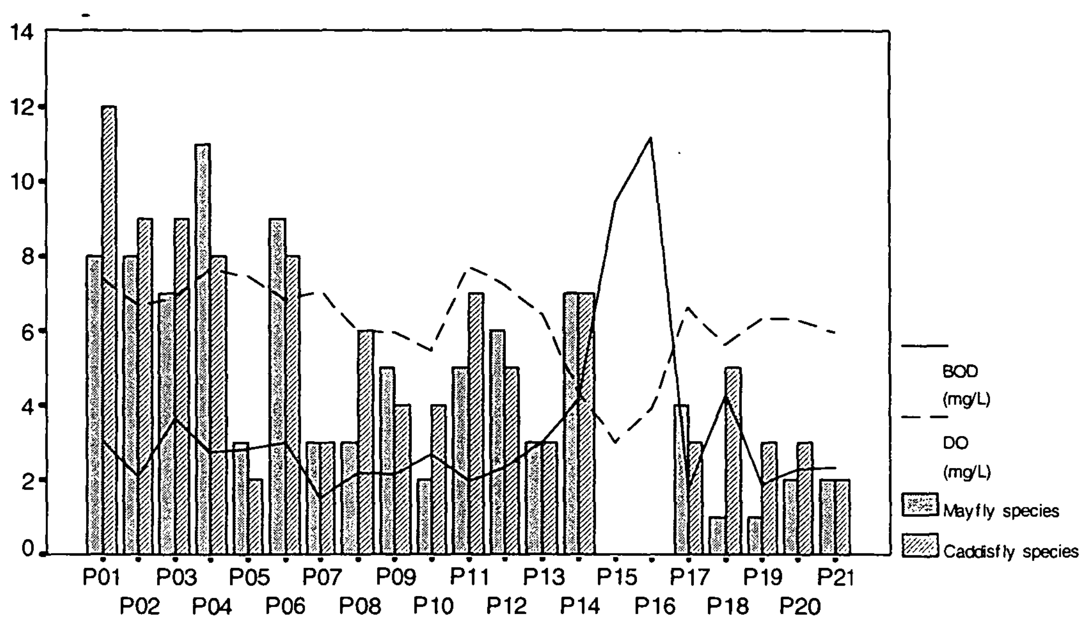


Figure 3.26 Spatial variation of mayfly and caddisfly species richness in relation to BOD and DO levels

Site P05 immediately above the Ubolratana large dam was the first site along the river Pong riverine which had noticeably low mayfly and caddisfly species richness (Figs. 3.1, 3.2). From site P09 onwards, mayfly and caddisfly species richness fluctuate markedly in response to impacts from river regulation, industrial effluent and community sewage. Figure 3.26 also illustrates an improvement of water quality zone along the Pong river profile, particularly around sites P11, P12 and P14. Sites P15 and P16 located within city boundary, in contrast, have neither taxa present. Site P17 where the river water does not through densely urban populated city areas, both orders were found.

It can be seen that species richness of mayflies and caddisflies (simply another "biometric" in this instance) vary in response to the chemical measures BOD and DO. At sites P15 and P16, the sharp increase of BOD and marked drop of DO levels corresponded to the absence of these two orders.

In some lower river reaches where the water quality improved, some caddisfly species are found to reappear. At site P18, when the DO increases and BOD reduces, the first caddisfly species to reappear are the free living forms, *Ecnomus* sp., *Phylocentropus* sp., *Polycentropus* sp. and the net-spinning *Macrostemum similior*. Concurrently, the mayflies occurring at the same site are *Litobrancha* sp. and *Caenis* spl.

It should be recognised here that the caddisfly species in lowland waters belong to three families, the Polycentropodidae, Ecnomidae and Hydropsychidae.

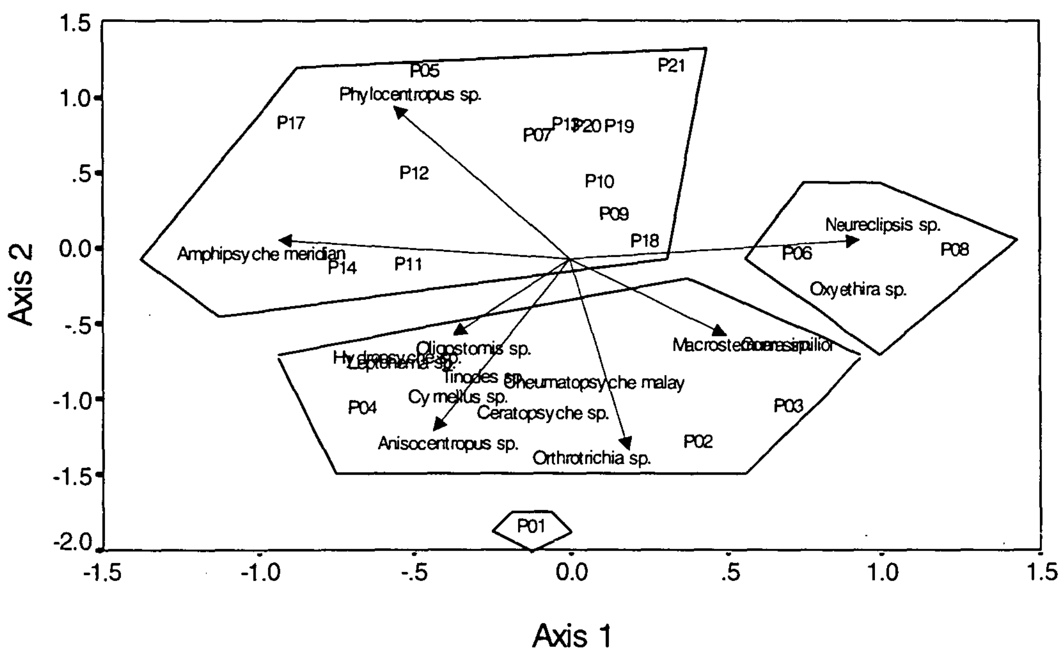


Figure 3.27 Sites ordination by HMDS (stress 0.1650) using caddisfly species density data, some species vectors significantly correlated to the ordination space are shown, and polygons indicate sites grouped by UPGMA

The sites were clearly separated by the multivariate analysis using average trichopteran species density (Fig.3.27). The less impacted sites are well separated from the rest. These sites can be further divided into three subgroups P01, P02 to P04, and P06 and P08, between which markedly different caddisfly species richness is apparent. Site P01 has the highest caddisfly species richness (12 species), sites P02 to P04, 8-9 species were found, and sites P06 and P08 6-8 species. The remaining sites had even fewer species.

The distribution of caddisfly species within the Pong catchment highlights some distributional phenomena. Certain species were limited to upstream waters, including *Anisocentropus* sp., *Goera* sp., *Leptocerus* sp., *Neureclipsis* sp., *Oligostomis* sp., *Oxyethira* sp. and *Tinodes* sp. The species which are most widespread over the catchment are *Polycentropus* sp. and *Phylocentropus* sp.

The correlation between the UPGMA group sites based on caddis species density data and environmental variables by DFA is shown in Table 3.3, and are mainly related to water temperature, water velocity, altitude and alkalinity. Sites at rather high altitude with cool waters and relatively high velocity will have a more abundant and diverse caddisfly fauna.

Table 3.3 Pooled within-groups correlations between discriminating environmental variables and canonical discriminant functions for UPGM site groups based on caddisfly abundance data

(Functions 1 and 2, P=0.0187 and P=0.1763 respectively when tested by Wilks' Lambda, 100% prediction UPGMA group memberships)

Environmental variables	Function 1	Function 2
WATERTEMP	-0.52190	-0.25136
VELOCITY	0.28662	-0.02087
LOGDISCHARGE	-0.17876	-0.02648
DEPTH	-0.13356	-0.04472
LOGTSS	0.13303	0.04489
LOGTURBIDITY	0.08716	0.02834
DO	0.06754	-0.00302
LOGCL	-0.08141	-0.08373
LOGTDS	-0.03088	-0.06710
LOGEC	-0.02889	-0.06010
ALTITUDE	0.38422	0.05266
LOGALKALINITY	0.20775	0.07556
PO_4	-0.00157	0.09014
NO_3	0.05555	-0.0399
RAINFALL	0.1784	0.1841
BOD	0.02939	0.00108
Canonical correlation	0.9885	0.9736
Percent variance explained	67.77	28.85

Stoneflies

Stoneflies were very rare in the Pong and only 24 specimens were found over the two-year samplings. Three species were represented: *Hesperlopera* sp., *Neoperla* sp. and *Phanoperla* sp. Only four sites in the upper catchment, P01 to P04, have all these species present. It appears that stoneflies existence is limited to the upper catchment where waters are relatively less disturbed.

Summary of key facts from analysis of each taxa group distribution

(1) A Common feature of the distribution of most benthic larvae species in the Pong catchment is that most are rarely found in the impacted waters. Only a few dipteran taxa are very abundant in such polluted waters.

(2) Chironomidae spp. is well predominant in response to organic pollution (BOD), while *Chaoborus* sp. is apparently abundant in high EC content waters.

(3) The riffle beetles (Elmidae) are much diverse and associated with less polluted waters.

(4) Among Odonatan species, *Aphylla* sp. is restricted to clean waters, and most Gomphidae species are likely to occur in less disturbed waters.

(5) The distribution patterns of water bug taxa are less strongly regulated by water pollution phenomena, and therefore they are less reliable indicators.

(6) Mayfly and caddisfly species distributions provide more valid information which can be used to quantify water pollution. Also, these two taxa are strongly related to BOD and DO levels.

(7) Stonefly species are rare in the Pong catchment, and only occur in upstream sites. With their limited species richness and restricted distribution, any relationship between stoneflies and environmental factors does not have much utility in environmental monitoring in northeast Thailand. This is a key point of difference with the temperate zone.

Conclusion and discussion

This foundation study has summarised the variation of the benthic fauna in the Pong catchment as well as the aquatic environmental changes through time and space. Numerous biotic changes were associated with environmental factors at various scales and help discriminate between seasonal and human impacts, which are very complex in nature.

Catchment water quality: consequences of seasonal regime and human impact

Like many tropical catchment waters, the impacts on water quality within the Pong catchment result from many sources. The impact origins are mainly from mixed uses of the water resource (Gopal and Sah 1993). In general, most water quality variables measured in this study had higher levels when compared to those prevailing in the temperate zone, e.g. in Smith and Maasdam (1994). In this study, the results also show that water quality of the Pong catchment varies markedly caused by a combination of factors, particularly seasonal flooding, land uses, damming and city sewage.

Seasonal regime is a prime natural source that alters water quality within the Pong catchment. The intensive rainfall during the wet season leads to massive surface run-off and suspended solids are carried into the catchment waters creating a dramatic change in water conditions. All of this particulate matter within the water column is then transported downstream. The riverbeds are disturbed by the heavy scouring effect, and thus all water bodies within the Pong river channel appear to be very turbid. Riverbanks with minimal retained vegetation cover experience severe erosion at this time.

In upstream sites, particularly where much land is cleared for crops, the water quality in the wet season mainly suffers from high suspended solids. However, between upper catchment sites the degree of water quality impact is considerably different. At sites with dense riparian vegetation, water quality is less disturbed by suspended solids (see Fig.3.4a). The importance of riparian vegetation is obvious here and similar to what is found elsewhere (e.g., in Fail *et al.* 1988, Cooper 1990, Osborne and Kovacic 1993, Johnson *et al.* 1997). Thus, it appears that the wider the buffer stripe, the less eroded soil will diffuse to water column (compare sites P01 and P02 in Fig.3.4a).

The major water physicochemical problems during the wet season are mainly from high water discharge and particulate matters or suspended solids. It appears that during the wet season, the natural impact is superior to human induce (point sources). During the dry season, the human influence is much more prominent on water quality changes. Both organic and inorganic pollutants in dry season increase to higher levels.

The human impact on water quality is obvious in the river reaches located close to the city area as in sites P15 and P16. These sites have a very marked contrast in both organic and inorganic water pollution between seasons. In dry months, they have very high average BOD (14.2 mg/L) while during the wet season, the average BOD level is less than half (6.4 mg/L). All inorganic contaminants, for example, EC, Cl, PO_4, SO_4 and alkalinity, are very high in summer, while during the wet season all are decreased in a similar manner to that of BOD level. In other words, the water pollution caused by human is much diluted by natural source-rainfalls.

The impact of damming and industrial effluent on water quality is also obvious in the Pong catchment. There is a marked degradation of river waters located above and below the dam (Fig.3.4b). Another distinct source of impact on catchment water quality is industrial effluent. The river water is distinctly degraded along the reaches located below industrial discharge points (Fig.3.4b). Both water regulation by damming and point sources discharged from factories cause a remarkable reduction of DO and elevation of BOD levels. Such pollution is especially critical during the summer months.

It appears that damming and industrial impacts are of lesser import in organically polluting the Pong catchment waters than the city sewage which contributes massively to the degradation of the Pong catchment waters (Figs.3.1 and 3.4b).

Even high water discharge in the rainy season causes a dramatic increase of suspended solids, but such discharge is still beneficial in improving water quality in some river stretches. The river reaches where organic and inorganic contaminants are mostly retained during summer months will be substantially diluted, as at sites P015 and P16.

It appears that mitigation of water pollution of the catchment mostly has to rely on the seasonal flooding regime. The most critical point source is city sewage. The water quality condition critically becomes under stress during summer, particularly in the hottest month of April.

Spatial classification of catchment water quality

Ordination and clustering methods can reveal relationships between sites in the catchment (as in Fig. 3.5a). Generally, the upstream sites were revealed to suffer from high water velocity and TSS contents within the water column. Organic pollution is detected by these methods and relates well only to the downstream sites which are located close to city areas (sites P14 to P16). The sites impacted by dissolved saline rock salts are well differentiated (sites P19 to P21, Fig.3.5a).

Interestingly, the positions of the sites clustered in the ordination space almost follow the catchment altitudinal gradients and organic-inorganic pollution level profile (see Figs.3.1 and 3.5a). The sites which receive much organic impact from human sources (P14 to P16) are most isolated from the rest.

The water quality vectors, which significantly correlate with the site ordination successfully indicate the water quality phenomena in responding to the grouped sites. In fact, the set of multivariate procedures applied here can better show the whole picture of spatial water quality changes in the wider catchment areas. This approach is more beneficial when compared to the conventional approach which only temporally and spatially elucidate each water quality variable at a time. Thus, study results suggest that using multivariate analysis method in quantifying water quality changes in a catchment scale is more advantageous. The sites arranged in the ordination space from multivariate analyses respond well to what is really occurring to water quality changes in those sites.

Multivariate analysis methods for this purpose are rather new (Chapman 1992), but their application in analysing environmental changes is now increasing, especially at the catchment-wide scale (Johnson and Gage 1997). For spatial water quality assessment, multivariate analyses have been successfully applied in quantifying changes of water quality, even at a nation-wide scale (Maasdam and Smith 1994).

This investigation and description of water quality variation in the Pong catchment has similarities with the catchment scale ecosystems research approach (Johnson *et al.* 1997, Allan and Johnson 1997). The results by this study show that certain changes of water quality are influenced by landscape profile and land-use interrelationships. The seasonal improvement of water quality within the catchment is primarily dependent on seasonal climate changes.

Finally, the results of study here clearly imply that quantification of water quality changes at a site has a very limited advantage particularly in tropical waters. Improvement of water quality in the impact sites as shown in this catchment relies on natural source-the annual rainfall regime. Therefore, further studies associated with water pollution in tropical catchment waters and the climate influence on the catchment-wide scale have to be well understood.

Benthic macroinvertebrate fauna abundance: the seasonal effect

The abundance of benthic larval assemblages in the Pong catchment is mainly conditioned by seasonal regime. Generally, macroinvertebrate species in tropical climate peak during the time prior to raining period (Anwar and Siddiqui 1988, Arunachalam *et al.* 1991). The pre-flooding period of the Pong catchment is between February to March. Even this study does not include sampling benthic animal in March, but it also implies a certain trend following that regime. The macroinvertebrate species richness peak found by this study is in February, which is 84 species.

The benthic organism abundance and species richness of the Pong catchment are mostly influenced by seasonal regime. The total catch of benthic organisms was reduced from 21355 (71.1%) in dry period to 8677 (28.9%) in monsoon season. Also, the total species richness during dry months is 106 species while in wet season is only 88 species. Such reduction of benthic larval assemblages mainly results from the high discharge waters (also with high TSS) during heavy raining months.

Generally, the influence of severe spate in causing reduction in benthic larvae in this study is similar to that reported by previous investigators elsewhere (Minshall 1988, Resh *et al.,* 1988, Townsend 1989, O'Connor and Lake 1994, Matthaei, Uehlinger and Frutiger, 1997). However, these studies were conducted in the temperate zone and there are few studies on the effect of flooding on benthic macroinvertebrate communities in tropical climate. Therefore, any direct comparisons between the results of this study and others cannot be directly made.

The decrease and increase of benthic larval species due to seasonal change

The study finds that each benthic taxon group is affected by spate to different degrees. The most susceptible group are mayflies whose species richness declines rapidly during the wet season. Hepatageniidae appears to be the most fragile family and is almost eliminated during the flooding season. For example, of the total 101 heptageniid larvae caught during two-year sampling, only one specimen was discovered in wet season. In fact, it is not the case of life cycle phenology, but rather it is due to the effect of spate. This family is abundant in some forested streams in the adjacent catchment of the Cheon river.

Although mayfly species richness is much reduced during the flooding season, its average density in mid-raining June is beginning to increase. This is mainly from an increase of certain caenid species, *Caenis* sp1 and Caenis sp2. These two species have their average density increasing to 72.7 and 18.5 specimens/m^2 respectively in June. This implies that within the order, flooding can have a different impact on each species.

Odonata and Trichoptera generally showed a remarkable reduction due to seasonal regime. The most affected taxa were the burrower dragonfly Gomphidae and filter feeding collectors caddisfly Hydropsychidae. The first decreased from 138 to 47 specimens, and the second taxon declined from 2473 specimens in the dry season to 392 specimens in the wet season. Even the average abundance of odonatans and trichopterans are reduced in wet season, however a few species increased in the rainy period, especially the odonatans *Aphylla* sp. and *Hagenius* sp., and the trichopterans *Cheaumatopsyche malayseinsis*, *Ecnomus* sp., *Phylocentropus* sp. and *Polycentropus* sp.

Unlike other benthic taxa groups, water beetle species richness peaks during the early rainy month of June (Fig.3.13a). In particular, several dytiscid and elmid larval species are abundant in this month. However, in August, when the waters are very turbulent, water beetle larvae are almost absent with only a few elmid larvae found during sampling. This incidence suggests that water beetles are very sensitive to high flooding regime, particularly with high water current.

Like water beetles, both species richness and density of water bugs are increased in June (see Fig.3.13a and 3.13b). The abundance trend of hemipteran taxa is very similar to that of water beetles. Even if this study did not conduct detailed studies of life cycle development of these two taxa, it appears that water beetles and water bugs increase their egg and nymphal development rate in the hottest month of April. Savage (1989) concluded that most hemipteran species are stimulated in their hatching when temperature increases, consistent with the observation of greater abundance of early instars of both water beetles and water bugs in June.

Unlike any other benthic groups, the density and species richness of Diptera was relatively constant. Diptera seems very tolerant to changes in the water discharge regime. Chironomidae spp. and *Bezzia* sp. exhibited little change in abundance during the contrasting wet and dry seasons. These two taxa are widespread in freshwater elsewhere and were also less impacted by inundation in other studies (Neckles *et al.*1990, Gladden and Smok 1990). Neckles *et al.* (1990) also reported that the water bug Corixidae and the water beetle Dytiscidae also persist relatively well despite extreme water level changes. In contrast, this study found that them to be still vulnerable to dramatic tropical flooding, although they will reappear in late rainy months along the riverbank as the waters become less turbulent.

Only certain species can resist severe seasonal flooding, and are typically those species with fixed retreats, anal claws and large appendages. In upstream sites where the water current is severe during heavy flooding, the caddisfly larvae *Macrostemum similior* with fixed retreats, elmid larva *Neonelmis* sp. with anal claws, and larvae tipulid species *Hexatoma* sp. with large appendages, are the only benthic larvae found. In contrast, during pre-stormy months with minus discharge, particularly in February, many diverse benthic groups are well distributed in upstream sites. The species found abundantly in this month includes the very fragile mayfly scraper larva *Arthroplea* sp., particularly in site P01 (127.8 specimens/m^2).

While most benthic macroinvertebrates are vulnerable to spate, a few species are very abundant during the rainy season. This may be viewed ecologically as a species-specific phenomenon. Although information about insect phenology is scarce in tropical Asia, it appears that certain species have a well-adapted life cycle responsive to climate changes. *Caenis* sp1 and *Caenis* sp2, for example, are well adjusted species by entering the early nymphal stage in the mid-rainy months. At this time, the swimming caddisfly species are also hatching, notably *Ecnomus* sp., *Phylocentropus* sp. and *Polycentropus* sp.

Indeed, life history and ecology information of tropical benthic species are very limited (Dudgeon 1995). This limitation is similar to elsewhere even in Great Britain where aquatic macroinvertebrate larvae taxonomy is well known (Elliot, Mumpesch and Macan 1988, Edington and Hildrew 1995). However, recent studies imply that most benthic fauna in the tropics is multivoltine (Jackson and Sweeny 1995, Marchant and Yule 1996, Yule and Pearson 1996). In north east Thailand, the evidence strongly suggests that multivotinism is typical of many taxa. Firstly, within each benthic taxon collected in the same month, the larvae are of usually mixed stages, and secondly, at every sampling occasion almost all benthic taxa groups can be found. There was no taxa group which absolutely disappeared in any sampling intervals, except in extremely flooding months.

Information on the effect of severe flooding on macroinvertebrate species is very limited in the tropic as Dudgeon (1995) noted recently. However, this study suggests that each benthic species is quite specific to seasonal change, particularly during early raining months. In late raining period with peak water flow (August to October), all benthic species, except dipteran taxa, are all similarly affected by severe flooding.

In summary, it is certain that different benthic taxa groups in the tropical Pong waters have different adaptive modes in responding to the effects of spate. Within each taxa group, each species also has different capability of life-cycle development towards seasonal spate. In early raining months, some species are well adapted to such seasonal water change and persist while some are eliminated. In late raining period with dramatically severe stormy waters, most larval assemblages encountered the same fate of being flushed out. In response to such contrasting water discharge, most benthic taxa adapt their life cycle towards seasonal stress by having a multivoltine reproductive cycle.

Relationships between water quality and benthic macroinvertebrate species richness

Water quality of the Pong catchment can be summarised as follows: Generally, the upper catchment waters suffer from soil erosion, water velocity and alkalinity (from dissolved carbonate rock salt), but not significant levels of organic (BOD) and nutrient (NO_3 and PO_4). In middle catchment where the waters are affected by damming, the BOD level is increasing and the DO begins to deplete (as shown in Fig.3.4a and 3.4b). Further downstream beyond the dam's influence, water quality starts to improve by decreased BOD and high DO content. Later, when the river flows across the city area, these two variables plus TDS markedly fluctuate. The BOD rises at to its highest value, the DO level rapidly drops and TDS begins to increase markedly.

Given the above water pollution scenario of the Pong catchment, the first account here associated with benthic faunal data is taxa richness. The upper catchment has maximum taxon richness, and the number of taxa gradually declines towards the lowest downstream catchment (see Figs.3.9 and 3.11). Generally, taxon richness is well related to organic and inorganic pollution. It also implies that organic (BOD) and inorganic pollutants (TDS and EC) may play a major role in conditioning the number of benthic species.

However, the above water pollution variables are not the sole factors which condition the presence and absence of a species. Other factors may be also involved, for example, channel morphology, flow, land use, riparian zone etc, as noted by many (e.g., Richards and Host 1997, Collier 1995, Allen *et al.* 1997). Thus, significant correlation found between the number of benthic species and water quality as mentioned above, is of limited use without considering other factors at a catchment-wide scale. There are some studies that fail to include these factors and eventually cannot yield any rigid conclusions, for example the study of Bales (1994).

Changes in species richness at a site through time and space can be sensitive to environmental change between sites, for example at sites P01 to P03 shown in Fig.3.11a, where species richness was very spatially varied.

Interrelationships between benthic species and water quality within a catchment

In this study, correlations between the benthic community and water quality are analysed by HMDS and UPGMA using three main different data sets. These are (1) average annual taxon density data, (2) average taxa density data for each of the wet and dry seasons, and (3) average annual density of each taxon group. Generally, these were all considered independently as I wished to find out which particular data set will contribute the best understanding of the association between benthic fauna and water quality variation.

More specifically, I wished to examine the annual and seasonal variations of both benthic taxa and water quality. Further, I also attempted to investigate the annual variation of each taxon group density within the catchment waters. As there is no background information available for the region, all analyses will be advantageous to some extent.

Sites P01 to P04 are always grouped together when using both the annual and two season data sets. These upstream sites have the greatest benthic taxa abundance. Major water quality pollutants of these sites as shown by significant vectors are TSS and water velocity for both annual and seasonal data. These sites are reflecting the perpetual effect of soil erosion. In other words, water pollutants of these upper catchment sites arise from physical sources (high TSS and velocity levels) rather than human induced origin (no significant BOD level found).

Whereas sites P01 to P04 consistently group together, other sites show a marked translocation within the ordination space depending on th edata set. The annual data set shows heavily polluted sites, P15 and P16, well separated from other sites and relating to BOD level. However, these two sites are poorly separated in wet and dry season analysis data sets. This is due to seasonal influence, and suggests that analysis using the combined data set is more advantageous as found by (Furse *et al.*1984, Ormerod 1987).

However, each seasonal data set provides some unique information. Each analysis does reveals a different benthic community variation in response to extreme environmental conditions (dry-wet and high-low flow). In this study, the seasonal analysis results show a clear differentiation of biological impairment of waters between seasons. These can be seen as follows.

Firstly, in the wet season only sites P01 to P04 are well differentiated from the others (Fig.3.15a), and relate certain benthic taxa with TSS, velocity and DO (Fig.3.15b and Fig3.15c). The other sites are rather clustered altogether and all suffer from higher nutrient and inorganic contents (Fig.3.15b). These high pollutant levels occurring in these sites show a good correlation to significant species found, mainly dipterans which associate with organically rich environments (Fig.15b).

Secondly, in the dry months, the analysis shows fine-scale separation between sites. The sites under the influence of the dam, P09 and P10, are well separated. The waters in these sites are almost stagnant during the dry season in which eutrophication frequently occurs except sometimes when receiving discharge from the dam. The riverbed sediment in these sites whenhigher water temperatures prevail (leading to nutrient bound deposits in anaerobic conditions) also activates the growth of Chironomidae larvae. In this scenario, the biological classification of the sites (Fig.3.12a) is promising.

Lastly, the upstream sites, P01 to P04, in the dry season have many sensitive species much more abundant as these sites have less organic pollution. Most downstream sites are grouped together as a result of severely high BOD waters. The most significant tolerant species associated with this latter group is *Chaoborus* sp. which shows high abundance in relation to EC, TDS and Cl levels. In this instance, *Chaoborus* sp. can be an indicator species which signifies organic and inorganic pollution of human origin.

The study suggested that several factors are involved in determining the distribution pattern of each taxon group. It needs more studies of all details of each species life-cycle, its ecology, species-environment interaction etc. Such an exercise is beyond the scope of this study (if so it may need several decades to finish), but initial accounts made by this study will still provide some invaluable information.

When comparing spatial distribution patterns between major taxon groups in the catchment, there are certain generalised patterns of distribution among them. Water beetles, water bugs and dragon-damsel flies all appear to be distributed in a similar fashion. They disappear from the very polluted waters, but exist sparsely in cleaner waters all over the catchment. However, none of these orders strongly correlates to water quality variables (Figs.3.18, 3.22 and 3.23). However certain species reflect water quality with their occurrence (presence/absence). For example, Elmidae larvae species which are mostly found in upstream cleaner water sites and one distinct dragonfly *Aphylla* sp. exists only in less polluted sites.

In contrast to the above three orders, dipteran data provides better ecological information in relation to water pollution. The most organically polluted waters always show high abundance of Chironomidae spp. and *Chaoborus* sp., whereas *Simulium* sp., *Hexatoma* sp., *Atherix* sp. and *Atrichops* sp. larvae are usually limited to less disturbed sites.

When analysing dipteran taxa data by HMDS (Fig.3.19), the sites appear rather scattered in the ordination space but a certain pattern can still be found. Organically polluted sites are divided from the less impact ones (the less polluted sites are P01, P02, P03, P04, P06 and P07 as in Fig.3.19). This suggests that dipteran taxa alone, can provide some useful information associated with pollution occurring within the catchment.

However, the abundance of mayfly and caddisfly taxa can show a better relationship with water quality disturbance. Species richness of both groups have almost the same trend and related well to water pollution (Fig.3.26).

May flies are never found in organically polluted sites, P15 and P16 during the two-year sampling (I even tried to find this order in several other microhabitats during two years at these two sites). When analysing mayfly data using average annual density, the sites arranged in the ordination space (as shown in Fig.3.25) reveals a fine-scale resolution.

Discriminant function analysis (DFA) reveals that velocity, depth and DO are major factors conditioning the occurrence of this order. The occurrence of mayfly at a site provides valuable information which reflects the magnitude of DO content in waters. The more diverse the mayfly species, the higher DO content in those water bodies (Fig.3.25).

Similar to the mayfly species pattern, caddis flies are widespread in the less polluted waters of the upper catchment. Unlike mayfly species, the distribution pattern of caddis flies in ordination space is more clearly related to water temperature, altitude and water velocity. The DFA analysis shows that water temperature is the most important factor which relates to the presence and diversity of caddis flies species. In upstream sites with diverse caddisfly species, forest cover is high and may lead to a cooler climate with relatively lower ambient temperatures which favour many caddis flies. This is also apparent in the Cheon catchment (especially in the control site). The more exposed lands in the lowland areas have a lesser diversity of caddis species. Caddisflies might arguably be an indicator of healthy forest cover.

Almost all the benthic taxa in the Pong catchment can be found on every sampling occasion, except in the period of heaviest flooding when most of larvae suffer from high water flow as reported elsewhere (Statzner and Higler 1986, Quinn and Hickey 1990). In this instance, quantification of the presence and absence or abundance of benthic species solely in the dry season yields adequate results for inter-site comparisons when resources, including manpower, are limited. Moreover, my results show that sampling the benthic community in the dry season best detects the influence of human impacts rather than in the wet season when natural perturbations are much more influential.

CHAPTER 4

The Performance of Biotic Score and Indices in Assessing Water Pollution: A Case Study in the Pong Catchment Thailand

Introduction- a brief review of score and indices systems

The assessment of water quality using benthic macroinvertebrate data is currently applied via two main approaches; firstly, by applying various indices and score systems to generate a metric which reflects the condition of the waterbody, and secondly, by employing multivariate analyses of community structure in order to identify communities typical of particular water conditions. The index and score systems are more popularly used among water authorities in continental Europe and North America (Johnson *et al.* 1993).

The index systems were first developed and derived from the classical German Saprobien system proposed by Kolkwitz and Marsson in 1909 (Metcalfe 1989). Water quality according to this system is classified into polysaprobic, alpha- and beta-mesosaprobic, and oligosaprobic zones in which each water body, respectively, ranges from highly polluted to saturated in oxygen with a very diverse fauna. The indicator taxa used in the Saprobien system are mainly bacteria, algae, protozoans, rotifers and some benthic macroinvertebrates.

Later, the Trent Biotic Index (TBI) was created by Woodiwiss in 1964 for monitoring water quality in the United Kingdom (Johnson *et al.* 1993). This index is mainly derived from the Saprobien system, but it focuses on using benthic macroinvertebrates as the indicator taxa. Modified versions of these two systems are now in use at regional and local levels throughout Europe.

However, the above index systems have a number of limitations. Firstly, they are effective only in local geographical areas, and secondly, taxa identification usually requires expert personnel. As an alternative to the index system, the score system was later developed. The first era of the score system is marked by the development of Chandler's Biotic Score (CBS) System in Scotland (Chandler 1970), followed by Chutter (1972) who proposed the use of a scoring system (The Chutter Score) for assessing water quality in South Africa. These two scoring methods were the first systems which exclusively used benthic macroinvertebrates for assessing water quality.

Nevertheless, in order to apply the above two score methods, the indicator taxa inevitably require species level identification, and then only apply to the species in a certain locality. Their subsequent broader application is still in question, for example, the CBS was found by Able (1989) to be effective in detecting organic water pollution, whereas Pinder and Farr

(1987) determined it to be insensitive. Research biologists tended to focus more on the necessity of high taxonomic resolution for more precise inferential information in assessing water pollution. Water quality managers, in contrast, require rather rapid biological methods (like the chemical) which are time-efficient and cost-effective.

To meet the above need, the Biological Monitoring Working Party system (BMWP) was derived. This score system uses benthic macroinvertebrate taxa resolved only to family level (Armitage *et al.* 1983). Each macroinvertebrate family is assigned a score according to its relative tolerance to polluted water (the score ranges 0-10). Later, the BMWP score was discovered to be less influenced by seasonality and sampling methods if it was divided by the number of families in the sample, and so it became the Average Score per Taxon (ASPT). The BMWP was found to be more sensitive in detecting organic pollution, but less discriminating in unpolluted waters (Bargos *et al.* 1990).

The BMWP is still in use in the United Kingdom and has addressed the short-comings of the score systems. The related Hilsenhoff's Family-Level Biotic Index was created and is currently widely used in North America (Hilsenhoff 1988). In Australia, the SIGNAL system (Stream Invertebrate Grade Number-Average Level) was proposed by Chessman (1995). The first method uses only arthropod taxa while the latter takes into account all macroinvertebrate groups. Both methods are designed for rapid bioassessment of water quality. The latter was recently tested, and was found to be quite promising (Growns *et al.* 1995). However, these two scoring methods require more evaluation conducted in other rivers apart from "shallow streams" in mountainous areas, for example, the deeper rivers in tropical climates. Consequently, these score systems will be tested in this Chapter.

Unlike the score system which was primarily based on pollution tolerant values, the index systems (sometimes called community structure indices) emphasise the variation of a species in a community sample. Washington (1984) reviewed eighteen commonly used indices (e.g., Shannon's, Magalef's, Simpson's, Menhinick's etc.) and found that each index has limited uses, and that all indices require extensively tests with respect to seasonal regime, sampling methods, sample size, duration of sampling and taxonomic level.

Among those indices, even the much recommended Shannon Weiner Index (e.g. UNEP, WHO, UNESCO and WMO, 1992) for use in water quality assessment was noted by Washington (1984) to be less than ideal. It is surprisingly therefore that current publications about the performance of these indices in evaluating water quality are rare.

In addition to the above score and index systems, a multimetric approach (multiple indices) has been recently proposed for use in the United States (see more details in Resh *et al.* 1995 and Barbour *et al.* 1995 and references therein). This new approach was influenced by the rapid bioassessment method developed by Plafkin *et al.* (1989). The multimetric approach was developed to rectify the limitations associated with individual metrics in use (e.g. Norris and George 1993). In fact, the multimetric approach to date is typically a combination of the former indices traditionally used. Its aim is to reduce the weakness or increase the strength of individual indices by combining them together. It is claimed that multiple indices can contribute more meaningful and effective ecological information for water resource planning (Barbour *et al.* 1995).

To date, the most commonly used multimetrics are richness measures, including total species richness, and Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa abundance (see details in Barbour *et al.* 1995). In addition to the EPT, individual metrics for Ephemeroptera, Trichoptera or Diptera abundance have also been adopted (DeShon 1995). All these are based on the conventional notion that degradation of water quality will also reduce the number of benthic species, particularly sensitive taxa (Spellerberg 1992, Resh 1995 *et al.* 1995). As benthic larval assemblages are sedentary in nature, changes in their community structure or population or species levels may well reflect water quality alteration (Rosenberg and Resh 1993, Norris and Norris 1995).

However, there has been very limited use made of benthic macroinvertebrate score and index systems in assessing water quality in southeast Asia. These countries are undergoing under rapid economic growth and suffer much from water pollution. Consequently, the development of aquatic pollution monitoring methods is urgently required in this region (Dudgeon *et al.* 1994). Recently, Resh (1995) proposed certain macroinvertebrate taxa metrics (mostly mixed with multiple indices) which might be used for monitoring water quality in newly industrialised countries.

Aims of study

In this chapter, I explore two issues:

(i) the performance of some score and index systems widely used in the temperate zone for their sensitivity to water conditions in the Pong catchment of northeast Thailand. The performance of these various scores and indices is compared using two independent sampling methods, based on qualitative (more strictly, semi-quantitative) and quantitative sampling. The qualitative samples were collected from edge waters, which are the most recogniseable biotope in all seasons apart from the riverbed habitat. The quantitative samples used in this chapter are the samples recovered from the river bottom.

(ii) to test whether a rapid, qualitative invertebrate sample will be equally informative about water quality compared to results derived from more conventional quantitative sampling collected along the same stretch of river. I intend to use the results from the quantitative method as the reference for comparison with the qualitative outcomes in terms of water quality.
(1)

Materials and methods

Comparison between sampling methods

(1) Qualitative versus quantitative sampling

Qualitative samples were collected from edge waters in February 1996 at all stations (Fig.3.1 Chapter 3) using a pond net (0.25x0.25 m opening with 500 μm mesh size). This qualitative sampling was conducted at the same times and places as that of quantitative sampling of the adjacent streambed in February 1996. The qualitative method was time standardised by using fifteen minute sampling times on the riverbank at each site, and therefore is arguably semi-quantitative.

All qualitative specimens were dislodged, aggregated and preserved in 70% ethanol. The specimens were then enumerated and identified to the lowest taxonomic level possible. All specimens are stored in the Department of Biology, Freshwater Biology Laboratory, Khon Kaen University, Thailand.

The quantitative samples used to compare with the qualitative data are the samples collected in February 1996 as detailed in Chapter 3. These two data sets will be evaluated through the application of multimetrics, scores and diversity indices.

(2) The score system

The score system used employed the methods of BMWP/ASPT (Armitage *et al.* 1983), SIGNAL (Chessman 1995), and the Hilsenhoff Biotic Index (Hilsenhoff 1988). In the former two score systems, each invertebrate family in a sample is assigned the score created by both methods, and all scores are summed and later divided by the number of families present in a sample. In contrast, under the Hilsenhoff Biotic Index system (which utilises only insect taxa) the family score is given and the sum score is divided by the total number of insect specimens caught. In this study it is modified slightly from Hilsenhoff's original concept which used only 100 organisms caught as the denominator, while in this study I used the total number of individuals caught. This is done so as to standardise the method by a timing factor (thirty minutes), rather than a specified count of 100 specimens. This study adopted the original family tolerance values from Hilsenhoff's concept.

(3) The diversity indices system

The diversity indices applied here are some of the most commonly used indices in water quality assessment. These are Simpson's, Margalef's, Shannon's and Hurlbert's PIE as follows:

(a) Simpson' s Index	=	$\sum n(n_i\text{-}1)/n(n_i\text{-}1)$
(b) Margalef's index	=	$S\text{-}1/\log_e n$
(c) Shannon Weiner index	=	$-\sum (n_i/n \log_e n_i/n)$
(d) Hurlbert's PIE =	=	$(n/n\text{-}1)\{(1\text{-}\sum (n_i/n)^2\}$

Where S=the number of species in a sample
n=the number of individuals in a sample
n_i=the number of individuals of a species *i* in a sample

(4) Testing the score and indices systems

The six replicates from the quantitative sampling at each site were combined as one sample for further analysis. The qualitative fifteen minute collection from the riverbanks was also regarded as one sample. These two data sources will be tested in parallel by using firstly, the fundamental indices and the richness measures (the so-called multimetrics), (number of individuals, species richness, family richness and EPT taxa richness). Secondly, the score and index systems were used. All these results will be compared between quantitative and qualitative sampling methods and sub-catchment locations.

Finally, the score and index results from both sampling methods were correlated to major water quality variables using Pearson product moment correlation. The water quality variables serve as the reference frame of comparison between score and index systems produced from the two sampling methods. All data were transformed to log (x+1) when necessary to improve normality prior to statistical analyses.

Assumptions required

There are some important assumptions to be agreed upon in this Chapter. Firstly, I explore the capacity of various score and index (metrics) systems to assess water quality in a tropical environment. If shown to be useful, they will assist current water quality monitoring programs in the region which mainly use chemical criteria. I have been working in river water quality monitoring in this region for more than ten years, and experience shows that chemical criteria have limited capacity to detect water quality changes unless assessing water pollution instantaneously at a point in space and time. Current protocols cannot quantify the degree of "healthy rivers" or even serve in the capacity as an "early warning system" (Cairns and van der Schalie 1980).

Secondly, the biotic scores and indices recommended for use in assessing water quality have been widely promoted (e.g. Abel 1989, UNEP, WHO, UNESCO and WMO 1992, Babour *et al.* 1995, Resh 1995) but those using macroinvertebrate data have rarely been tested in tropical Asian waters. This may be due to the fact that the use of macroinvertebrate fauna in evaluating water quality is quite new since it has become popular only since the mid-1980s (Resh 1995). It may also be due to the limited knowledge of benthic larvae taxonomy in the region.

Thirdly, I agree with Norris and Norris (1995) who listed major complaints regarding the use biological methods in assessing water quality. These can be summarised as (i) one often face difficulties with less standardised methods, thus merging uncertainty in interpreting results of water quality impacts, (ii) the biological monitoring program or project is rather costly, labour intensive and time consuming, and (iii) the results are difficult to comprehend unless simplified, since sophisticated multivariate analyses are used. All these obstacles led me to test some current biotic scores and indices to attempt to simplify the biological interpretation and whether this will work in parallel with the simultaneous chemical criteria.

Lastly, I am aware that biotic indices and scores cannot be used alone and have to be incorporated with physical and chemical parameters (Friedric *et al.* 1992). Further, when using biological indices the nature of water pollution has to be well understood (Norris and George 1993). In this instance, I included the major physicochemical water quality parameters which are well recognised in this region and therefore related all scores and indices to these chemical variables. This is also done to intercalibrate the scores and indices results with reference to the physicochemical parameters.

Results

Multimetric approach

(1) Benthic animal abundance

The total number of benthic specimens collected by qualitative and quantitative methods were very different (t_{20}=6.00, P<0.001). The combined six replicates samples recovered by the Ekman grab had a total of 4215 individuals, mainly of Diptera (58.5%), Trichoptera (15.8%) and Ephemeroptera (9.3%), while the adjacent qualitative sample caught 1208 organisms, mostly Hemiptera (43.2%), Ephemeroptera (19.4%) and Odonata (16.2%).

Figure 4.1 illustrates the total number organisms caught by the two sampling methods from all sites in the Pong catchment in February 1996. The difference in efficiency in terms of catch size of benthic organisms was most apparent at the upper catchment sites. At sites P02 and P03, for example, the quantitative method caught 843 and 844 specimens, while the qualitative approach sampled only 31 and 68 organisms respectively. However, there are other sites in which both methods yielded similar numbers of specimens, for example, sites P06 and P18 to P21 (Fig. 4.1).

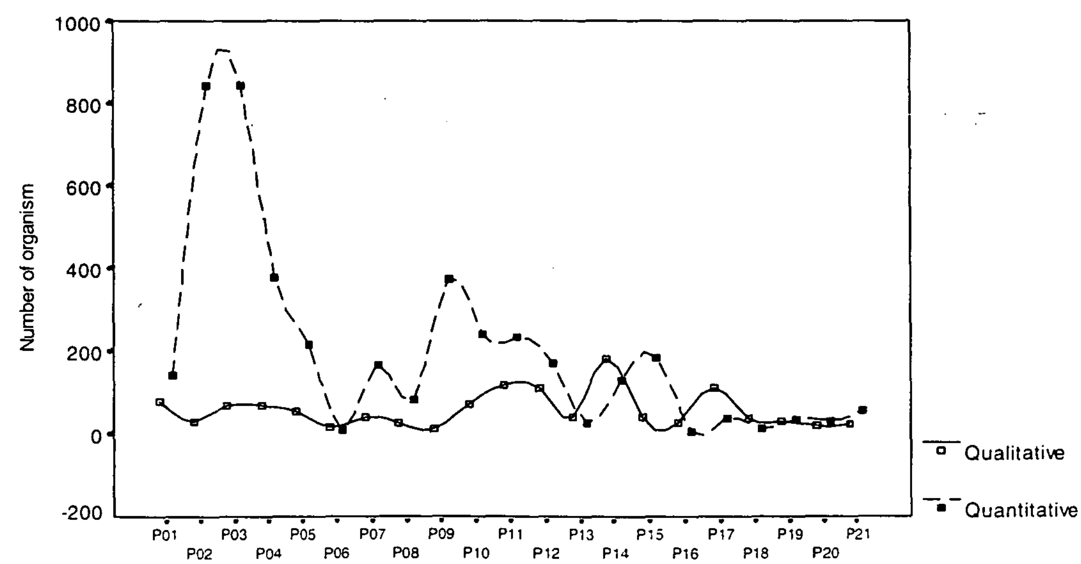


Figure 4.1 Comparison between total numbers of benthic organism caught by qualitative and quantitative sampling methods

(2) Species richness

The cumulative number of benthic species sampled by the qualitative method (n=60) is not significantly different from the quantitative method (n=53) (t_{20}=2.05, P=0.054). However, taxa composition does differ greatly between the two sampling methods. The quantitative method yielded a high abundance of Trichoptera, Ephemeroptera and Odonata, while the qualitative samples mainly consisted of Hemiptera and Odonata.

The most common species from qualitative samples belong to hemipteran taxa, while the species from quantitative samples were almost evenly divided between Trichoptera, Ephemeroptera and Odonata. In terms of individuals, caddisfly larvae dominated the quantitative samples, while water bugs had great abundance in the qualitative samples (Table 4.1).

The number of species from edge-water samples does not change with position along the catchment ($F_{2,18}$=0.8100, P<0.4604) (Fig.4.2a). The upper, middle and lower catchment sampling sites when sampled qualitatively considerably have similar benthic species numbers. Their average species richness are 12.3±2.3, 10.6±3.0 and 10.7±3.5 respectively (mean±SD).

In contrast, species richness recovered by quantitative sampling did differ along the catchment ($F_{2,18}$=7.9603, P<0.0033) (Fig.4.2a). The upper catchment waters have greater species richness than the middle and lower catchment sampling sites, which had 13.5±7.2, 7.4±2.6 and 4.1±1.5 species respectively (mean±SD).

Table 4.1 Species composition between quantitative and qualitative sampling methods

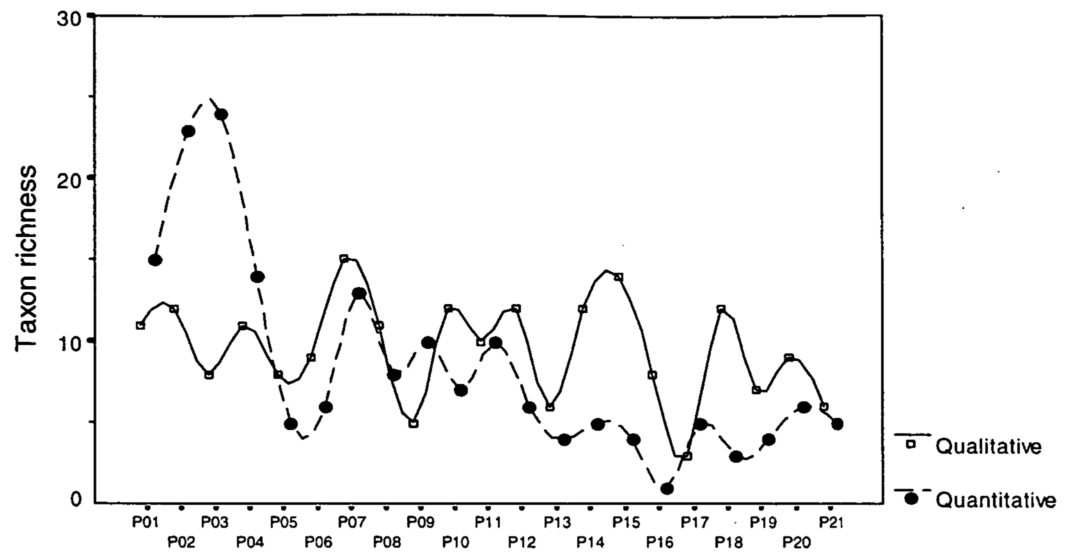
(numbers in bold indicate dominant taxa of each sampling method)

Taxa	Quantitative		Qualitative	
	No of species	**(%)**	**No of species**	**(%)**
Coleoptera	7	13%	6	10%
Decapoda	1	2%	1	2%
Diptera	5	9%	2	3%
Ephemeroptera	**10**	**19%**	**7**	**12%**
Hemiptera	5	9%	**24**	**40%**
Odonata	**10**	**19%**	**15**	**25%**
Oligochaeta	1	2%	0	0%
Lepidoptera	0	0%	1	2%
Plecoptera	1	2%	0	0%
Trichoptera	**12**	**23%**	2	3%
Veneroida	1	2%	2	3%
Total	53	100%	60	100%

After aggregating benthic taxa at the family level, the total family richness from edge-water and streambed samples were found to be very similar (31 and 34 families respectively). However, the richness of benthic families collected by both methods is significantly different between sites (t_{20}=11.39, P=0.0001), Fig.4.2b. The quantitative method showed a significant variation of benthic families between catchment sites ($F_{2,18}$= 8.2378, P=0.0029) (Fig.4.2b) with streambed samples having greater family richness (12.3±5.9)in the upper sites than the middle (7.4±2.6) and lower catchment sites (4.1±1.6) (mean±SD).

The edge-water samples, on the other hand, did not reveal any significant difference in mean benthic family richness according to catchment position ($F_{2,18}$=0.1836, P=0.8338) (Fig.4.2b). The edge-water organisms found in upper, middle and lower sampling sites yielded 8.12±2.3, 7.6±2.9, 7.3±3.4 (mean±SD) families respectively.

(a)



(b)

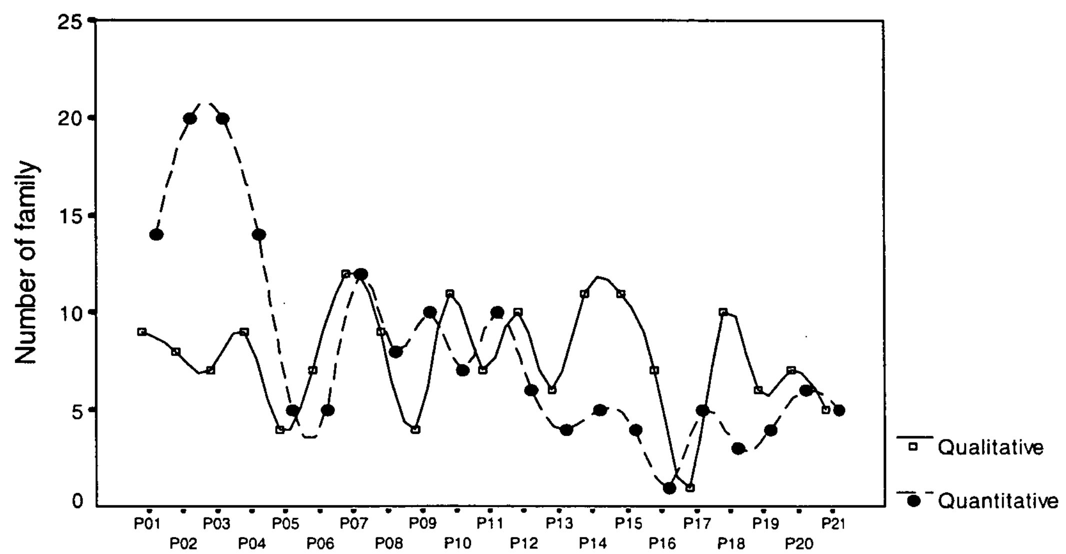


Figure 4.2 Total numbers of (a) species, and (b) families, comparison between qualitative and quantitative methods in all sampling sites

The most abundant benthic individuals grouped by family level from the qualitative method are Gerridae (21%), Baetidae (17%), Corixidae (16%) and Protoneuridae (13%), whereas those of the quantitative samples are Chironomidae (47%), Hydropsychidae (13%) and Corbiculidae (6%). Most organisms caught by qualitative edge-water samples were from middle and downstream sites, whereas the quantitative streambed samples had more individuals in upstream sites.

This is the first demonstrated difference between results derived from two contrasting sampling methods for a southeast Asian river. Clearly, the fundamental metrics, species and family richness estimated from the two different sampling methods are quite different from each other.

The quantitative samples generated taxon richness values which reflected variation between catchment position much better than the qualitative samples. The taxa composition from both methods was also very different but this is not unexpected given that the methods targetted different subsets of the aquatic fauna.

Correlations between taxa richness and water quality variables

The species richness from each method correlated differently to major water quality variables. There was no significant correlation between species richness from edge-water samples and major water quality parameters (Table 4.2). The species richness from quantitative data, however, revealed significant negative relationship with PO_4, NO_3 and positive with DO.

Table 4.2 Correlations between species richness from edge-water and streambed samples and major water quality variables *(numbers in bold denote significant correlation)*

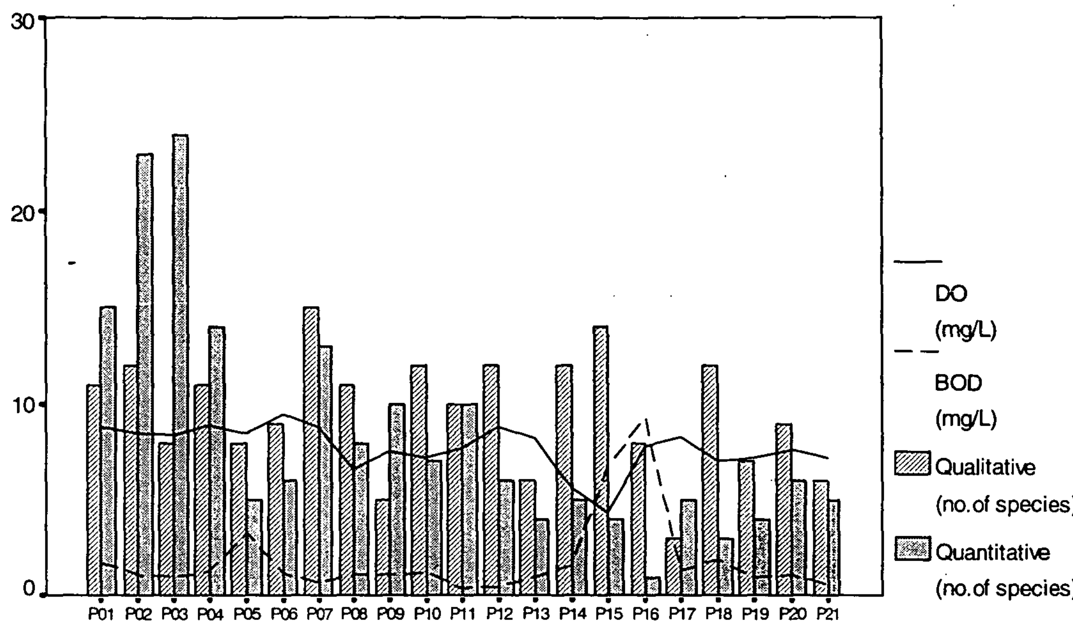
Major water quality variables	Quantitative		Qualitative	
	r	*P*-value	*r*	*P*-value
EC (micro*S*/cm)	-0.1782	0.220	-0.2418	0.145
NO_3 (mg/L)	**-0.5357**	**0.006**	0.0312	0.447
PO_4 (mg/L)	**-0.6615**	**0.001**	-0.024	0.459
TSS (mg/L)	-0.3173	0.081	-0.0122	0.479
DO (mg/L)	**0.4312**	**0.011**	-0.1961	0.197
LOGBOD (mg/L)	**-0.5396**	**0.006**	0.0639	0.392

Streambed samples (Figure 4.3) showed a distinct reduction of benthic species particularly in degraded water quality sites of the Pong catchment. The number of species from edge-waters did not, on the other hand, markedly fluctuate in response to water pollution.

The most polluted site was P16. Its average BOD value in February rose to 9.3 mg/L, nutrient levels were also high with NO_3 at 2.0 mg/L and PO_4 at 1.4 mg/L. Only one taxon group, Chironomidae spp., with five individuals, was recovered from streambed samples. Simultaneously at this site eight species (with 28 individuals) were in edge-water samples: the mayfly *Baetis* sp2 (n=5 individuals), the water bugs *Ctenipocoris* sp.(n=1), *Mesovelia* sp.(n=4), *Micronecta* sp.(n=6), *Halobates* sp.(n=1), damselflies *Ischnura* sp.(n=7) and *Pseudagrion* sp1 (n=2), and the freshwater shrimp *Macrobrachium landchestri* (n=2).

The DO level in site P16 (Figs.4.3a, 4.3b) was considerably elevated, averaging 7.8 mg/L, and probably resulted from the photosynthesis of the flourishing unicellular pollution indicator alga *Microcystis* sp. The waters in this site during sampling had a rather eutrophic condition, thus the DO value was high when compared to site P15. In this respect, a high DO level did not necessarily correspond to high benthic taxa abundance or diversity.

(a)



(b)

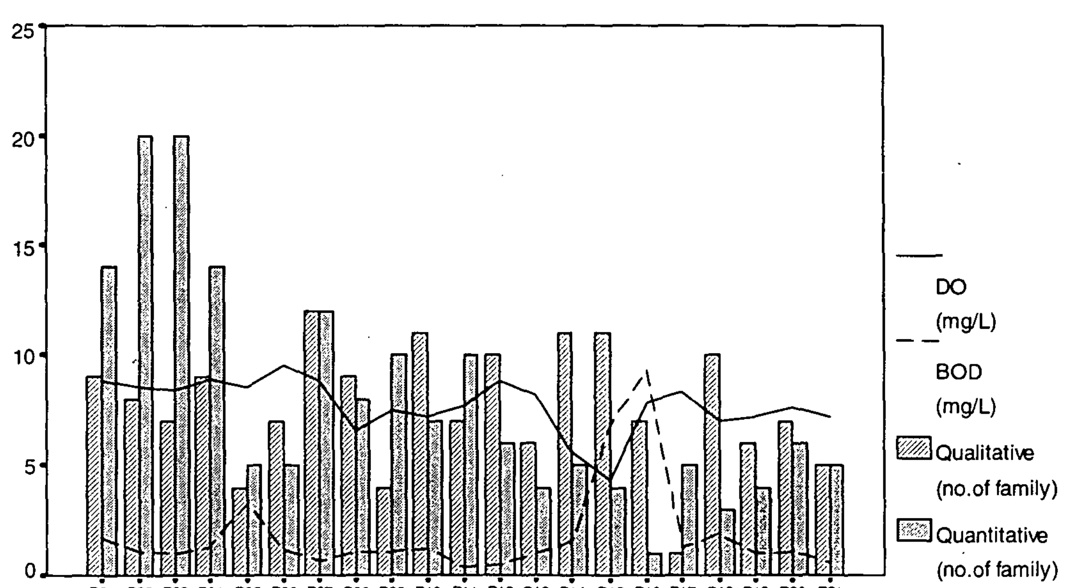


Figure 4.3 Spatial variations of (a) species and (b) family numbers sampled by quantitative and qualitative methods, and DO and BOD levels in corresponding sampling sites

Correlations between the numbers of families from streambed or edge-water samples and major water quality variables were similar when using species richness measures (Tables 4.2 and 4.3). Four water quality parameters were related to the number of families recovered by quantitative sampling, but there was no significant correlation found from qualitative data (Table 4.3).

Table 4.3 Correlations between numbers of family from edge-water and streambed samples and major water quality variables

(numbers in bold indicate significant correlation)

Major water quality variables	Quantitative		Qualitative	
	r	*P*-value	*r*	*P*-value
EC (microS/cm)	-0.1706	0.230	-0.2202	0.169
NO_3 (mg/L)	**-0.5710**	**0.003**	0.0522	0.411
PO_4 (mg/L)	**-0.6807**	**0.001**	0.0164	0.472
TSS (mg/L)	-0.3305	0.072	0.0681	0.385
DO (mg/L)	**0.4102**	**0.022**	-0.2825	0.107
LOGBOD (mg/L)	**-0.5525**	**0.005**	0.0463	0.421

Ephemeroptera, Plecoptera and Trichoptera (EPT) index

Over the whole catchment, the streambed samples yielded a total of 9 EPT species (7 mayfly and 2 caddisfly species), while the edge-water samples yielded 23 EPT species (10 mayfly, 1 stonefly and 12 caddisfly species).

Ephemeroptera in qualitative edge-water samples were mostly *Baetis* sp1 (36%) and *Baetis* sp2 (45%), whereas four mayfly species were abundant in quantitative streambed samples, *Baetis* sp2 (21%), *Caenis* sp1 (24%), *Caenis* sp2 (21%) and *Choroterpes* sp.(18%).

The caddisfly species composition of streambed samples (n=666 individuals recovered), was *Cheumatopyshe malaysiensis* (78%), *Ecnomus* sp.(5%), *Macrostemum similior* (5%) and *Orthotrichia* sp.(3%). Only four specimens were found in all the combined edge-water samples, a single *Hydropsyche* sp. and three *Leptocerus* sp. This implies that caddis flies in edge-waters are poorly sampled by this method, although they are probably more abundant in streambeds anyway.

Table 4.4. summarises percentage composition of EPT families grouped by EPT orders. The edge-water samples had fewer EPT families (n=6), while a total of 15 EPT families were recovered from streambed samples. Most EPT individuals from streambed samples belonged to the caddisfly family Hydropsychidae, while the edge-water samples had mostly the mayfly family Baetidae in abundance.

Table 4.4 Comparative percent composition of EPT individuals between quantitative and qualitative samplings

Order	Family	Quantitative (%)	Qualitative (%)
Ephemeroptera	Baetidae	9.2	84.8
-	Caenidae	16.7	5.5
	Ephemeridae	1.6	0.0
	Heptageniidae	0.1	0.1
	Leptophlebiidae	6.5	3.4
	Potamanthidae	2.7	0.0
Plecoptera	Perlidae	0.3	0.0
Trichoptera	Calamoceratidae	0.2	0.0
	Ecnomidae	3.0	0.0
	Hydropsychidae	52.3	0.4
	Hydroptilidae	2.1	0.0
	Leptoceridae	0.5	1.3
	Polycentropodidae	3.1	0.0
	Psychomyiidae	0.1	0.0

When relating EPT taxa richness with BOD the most critical water pollution variable in the Pong catchment, EPT richness from quantitative samples showed a significant negative correlation (r=-0.77, P=0.001). The EPT richness from edge-water samples, in contrast, showed no significant association with BOD (r=-0.28, P=0.108). Figure 4.4 illustrates the spatial trend of EPT taxa richness in relation to the BOD levels along the Pong catchment profile. The EPT species found in streambed samples (quantitative) markedly fluctuated following variation levels in BOD.

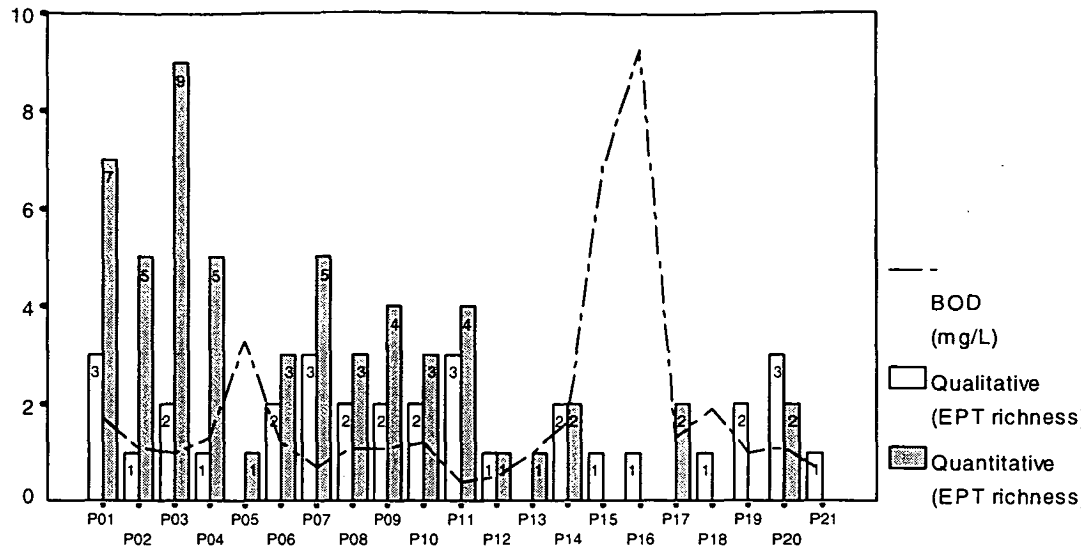


Figure 4.4 EPT taxa richness of qualitative and quantitative samples, and correspondingly, BOD levels in each sampling site
(numbers at the top of the bars are the number of EPT species found in each sampling site)

The EPT taxa richness from streambed samples was also positively related to DO value (r=0.44, P=0.022), while no significant correlation was found between EPT richness from edge-water samples and DO (r=0.00, P=0.500).

Only two major water quality variables, BOD and DO, showed a significant relationship to EPT taxa richness in streambed samples. There was no significant correlation found between EPT taxa richness of both edge-water and streambed samples and other major water quality pollution variables, such as EC, NO_3, PO_4 and TSS.

Percent EPT composition (%EPT individuals/total abundance), relates to major water quality variables. Percent EPT taxa composition from quantitative samples shows association with BOD (r=-0.49, P=0.012), EC (r=-0.53, P=0.007) and PO_4 (r=-0.45, P=0.021), but not with TSS (r=-0.12, P=0.305) and NO_3 levels (r=-0.17, P=0.236). There was no significant correlation between percent EPT taxa from edge-water samples and any of these water quality variables.

Another EPT index uses only EPT family richness to correlate with major water quality variables. Using this approach, EPT family richness from quantitative samples was also positively correlated to DO (r=0.42, P=0.028), and negatively related to BOD (r=-0.39, P=0.042). There was no correlation between quantitative EPT richness and TSS, NO_3 and PO_4. The EPT family richness derived from qualitative edge-water samples did not significantly relate to any water quality variable. Figure 4.5 illustrates the number of EPT families sampled at each site and its spatial trend against corresponding BOD and DO values.

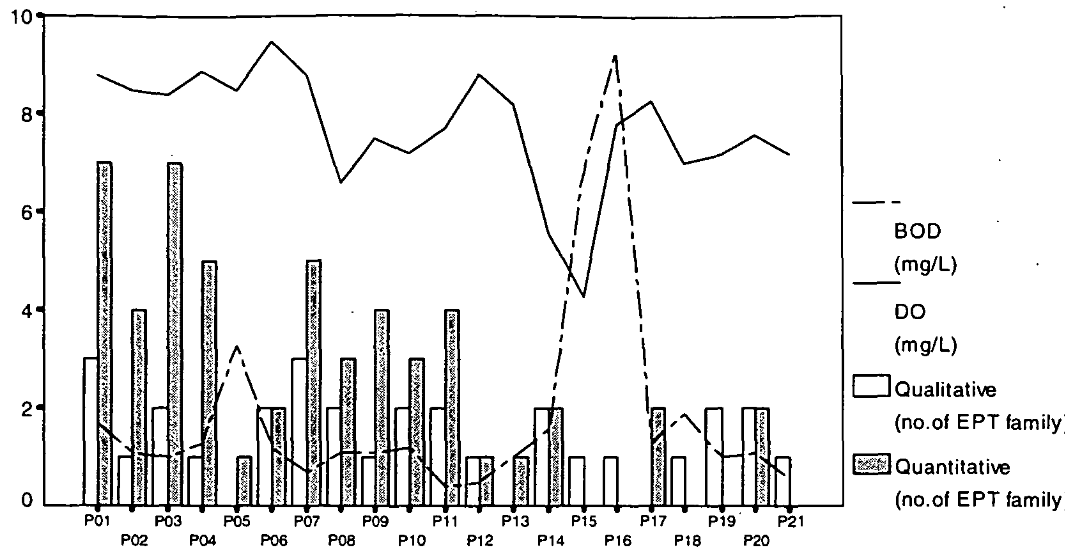


Figure 4.5 Numbers of EPT family from qualitative and quantitative samples, and correspondingly, average BOD and DO levels in each sampling site

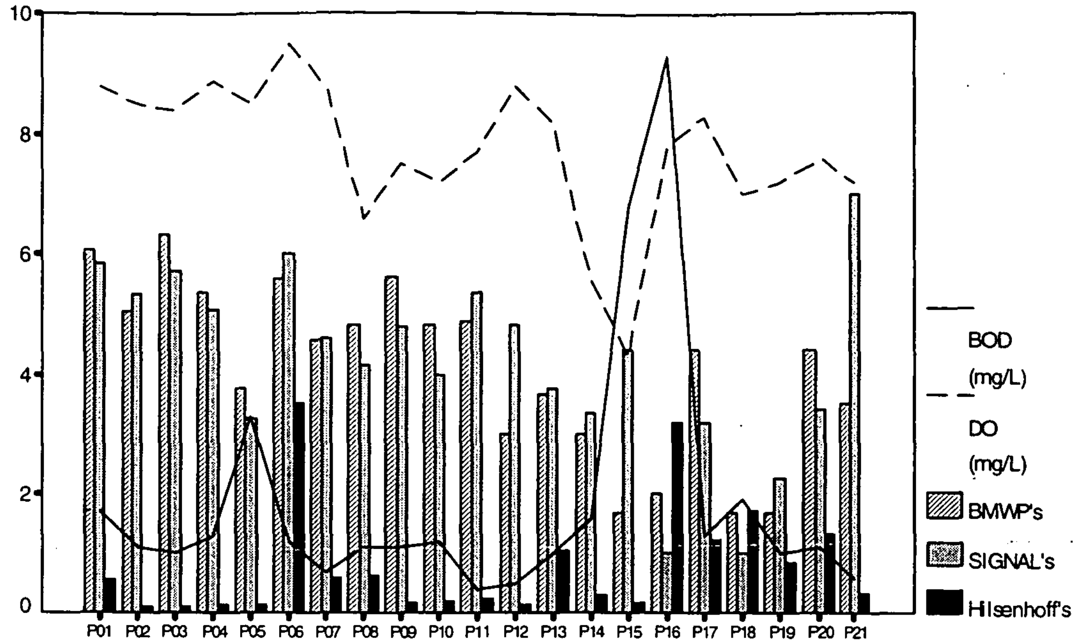
The scoring systems

Each scoring system used here approaches the quantification of water pollution impacts in different ways. The BMPW (ASPT) and SIGNAL scores are lower when water quality is degraded, while the Hilsenhoff's is the higher.

Both quantitative and qualitative sampling methods generated different trends of biotic scores when these three family level biotic scores were applied. The scores derived from quantitative streambed samples contributed more reliable results than the qualitative edge-water samples (compare Figs.4.6a and 4.6b). The biotic scores from quantitative samples followed the trend of water pollution at a site (Fig.4.6a), whereas the scores from data did not obviously relate to spatial water quality variation (Fig.4.6b).

Although all biotic scores from quantitative samples tended to agree with trends in water pollution, they showed different correlation values with pollution parameters. BMWP(ASPT) and SIGNAL scores were significantly negatively related to BOD (organic pollution), while Hilsenhoff's was not. Instead, Hilsenhoff's score featured high association with NO_3 and PO_4 levels. All three score systems were well related to PO_4 values.

(a)



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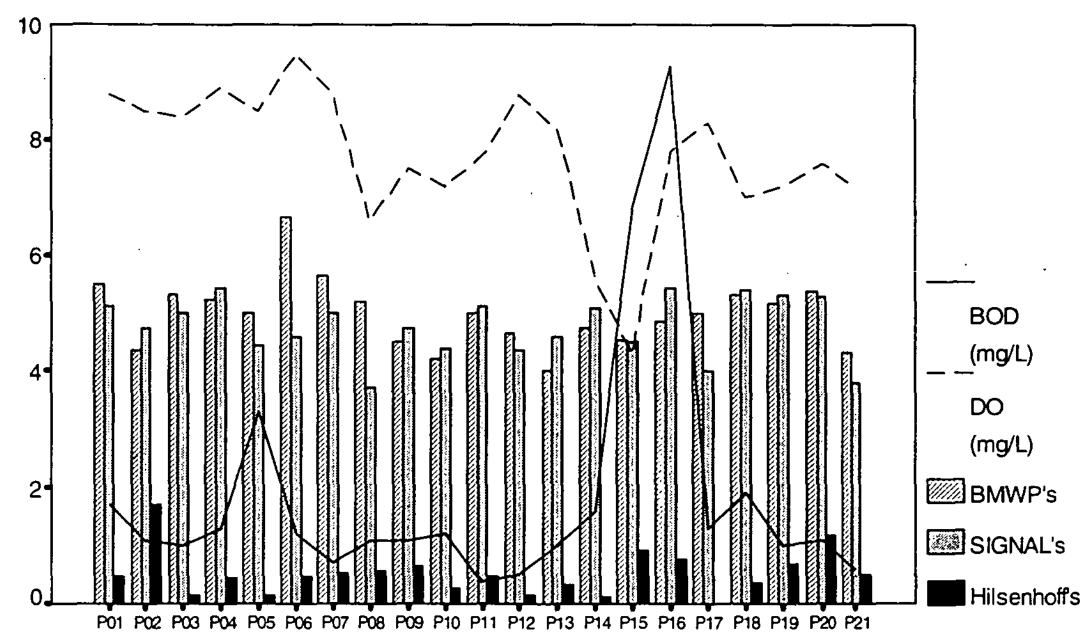


Figure 4.6 Results of biotic scores from (a) streambed, and (b) edge-water samples, correspondingly, average BOD and DO levels in each sampling site

Only BMPW(ASPT) showed positive correlation to DO. There was no correlation between all three score systems with EC and TSS. All of these scores failed to detect inorganic pollutants (EC and TSS). Rather, these scores reflect the intensity of organic parameters. Tables 4.5 and 4.6 summarise the association of these scores with various water quality parameters, tabulated by streambed and edge-water samples.

Diversity indices

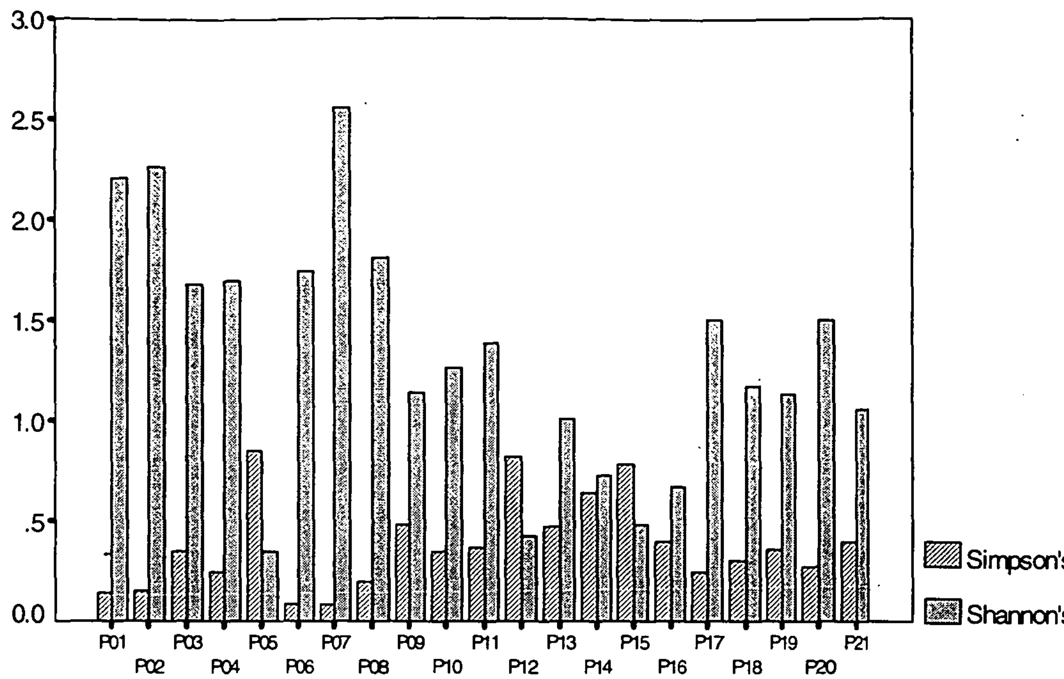
Of the two indices Simpson's (D) and Shannon Weiner's (H'), the former has high values when the benthic taxa are diverse, while the latter is high when taxa has reduced diversity. Both indices responded differently when using quantitative streambed samples. Firstly, values of H' were significantly different between catchment position, i.e. upstream, middle and downstream sites ($F_{2,18}$=5.444, P=.0142), while the D value did not show any significant variation in this regard ($F_{2,18}$=2.107, P=0.1505).

The H' from quantitative samples was significantly positively well related to DO and negatively to BOD (Table 4.5). Most polluted sites have lower H' values, while the less impacted sites have higher H' values (Fig.4.7a). Simpson's index from quantitative samples showed significant correlation only with DO (Table 4.5).

With edge-water sample data neither index showed systematic variation in relation to catchment landscape and water pollution situation (Fig.4.7b and Table 4.6). There was no correlation between H' and D and any water quality variable when using data from qualitative samples (Table 4.6).

The last two indices, the Hurlbert PIE and Margalef's, failed to discriminate benthic faunal diversity between catchment sites when using either quantitative or qualitative samples (Figs.4.8a, 4.8b). When using quantitative samples, only the Hurlbert PIE showed a significant relationship with DO level (Table 4.5). The Margalef's index, however, did not show any marked correlation to any water quality change or topographical landscape when using either streambed or edge-water samples (Tables 4.5, 4.6).

(a)



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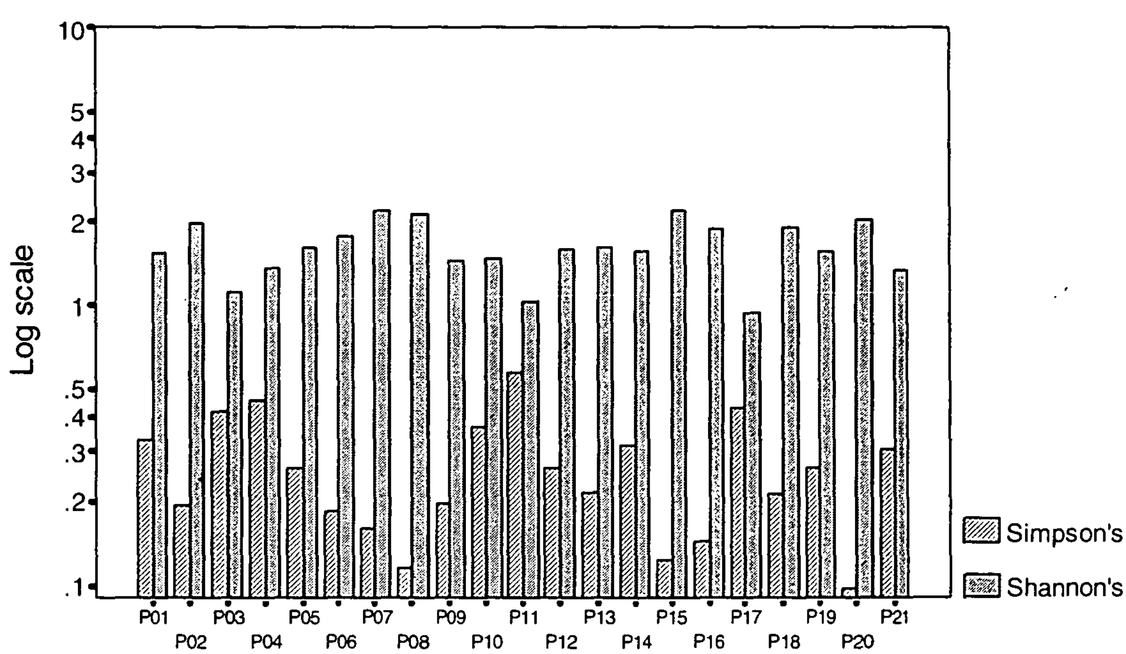
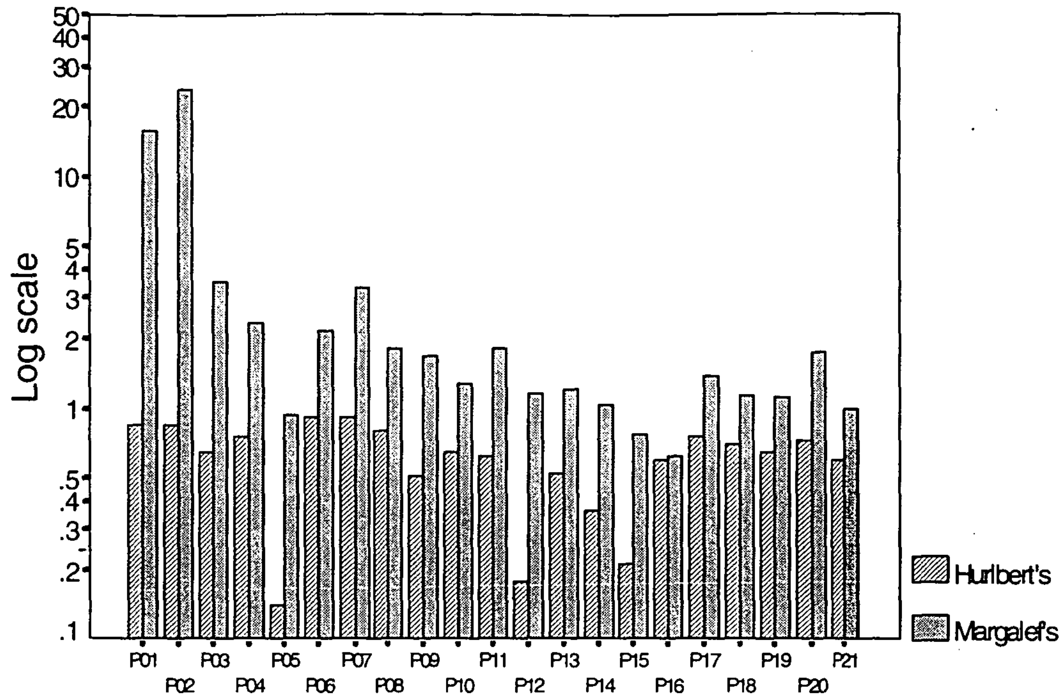


Figure 4.7 Simpson and Shannon Weiner diversity indices derived from (a) streambed, and (b) edge-water samples, in all corresponding sampling sites

(a)



(b)

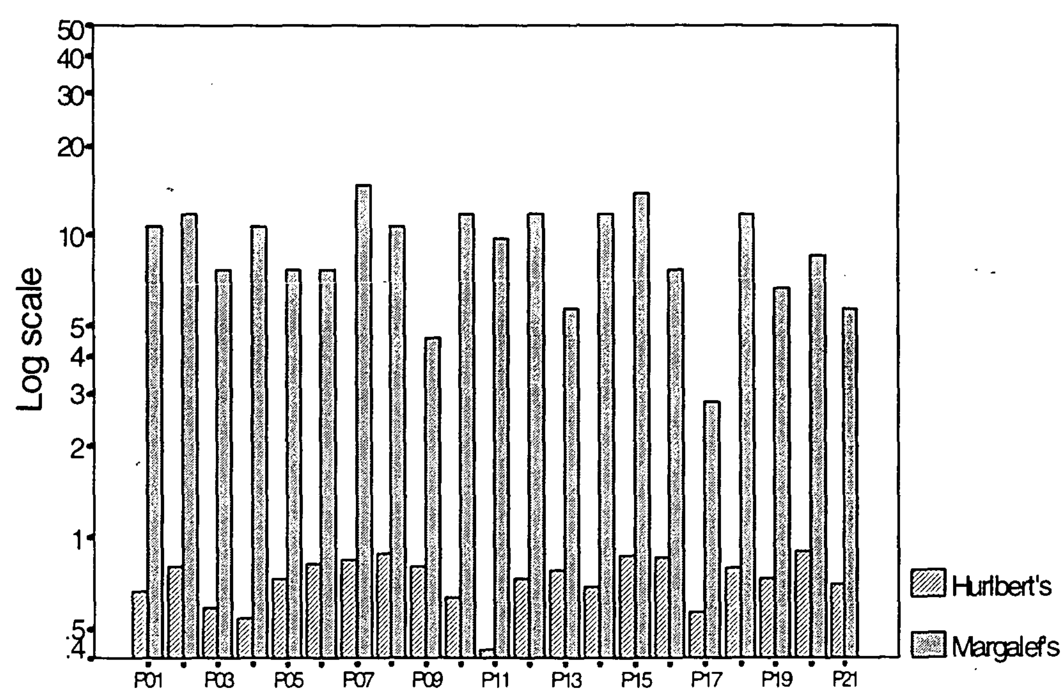


Figure 4.8 Hurlbert PIE and Margalef diversity indices of (a) streambed, and (b) edge-water samples, in all corresponding sampling sites

Table 4.5 Pearson-product moment correlations (r) between biotic scores and indices and major water quality variables when using streambed (quantitative) data

(numbers in bold show statistical significant correlations)

Water quality variables	BMWP's	SIGNAL's	Hilsen-hoff's	H'	Hurlbert's PIE	Marga-lef's	Simp-son's
LOGEC	-0.3068 P= .088	-0.0493 P= .416	-0.0742 P= .375	0.1659 P= .236	-0.0828 P= .361	-0.1038 P= .327	0.0828 P= .361
NO3	-0.227 P= .161	-0.3576 P= .056	**0.732** **P= .0001**	0.0936 P= .343	0.1259 P= .293	0.0126 P= .478	-0.1259 P= .293
PO4	**-0.4312** **P= .025**	**-0.5787** **P= .003**	**0.6308** **P= .001**	0.2593 P= .128	0.0012 P= .498	-0.0009 P= .498	-0.0012 P= .498
LOGTSS	-0.3463 P= .062	-0.3315 P= .071	0.3387 P= .067	0.364 P= .052	-0.2856 P= .105	-0.2436 P= .144	0.2856 P= .105
DO	**0.5574** **P= .004**	0.2777 P= .111	0.2255 P= .163	**0.4496** **P= .020**	**0.4209** **P= .029**	-0.202 P= .190	**-0.4209** **P= .029**
LOGBOD	**-0.4238** **P= .028**	**-0.5226** **P= .008**	**0.3501** **P= .060**	**-0.3846** **P= .043**	-0.2768 P= .112	0.0712 P= .380	0.2768 P= .112

Table 4.6 Pearson-product moment correlations (r) between biotic scores and indices and major water quality variables using edge-water (qualitative) data

Water quality variables	BMWP	SIGNAL	Hilsen-hoff's	H'	Hurlbert's PIE	Marga-lef's	Simpson's
LOGEC	-0.1602	0.1359	0.4051	0.0693	0.1446	-0.1828	-0.1446
	P= .488	P= .557	P= .068	P= .765	P= .532	P= .428	P= .532
NO3	0.235	0.2871	0.1021	0.2483	0.2956	-0.0206	-0.2956
	P= .305	P= .207	P= .660	P= .278	P= .193	P= .929	P= .193
PO4	0.0095	0.351	0.1373	0.2253	0.2724	-0.0422	-0.2724
	P= .967	P= .119	P= .553	P= .326	P= .232	P= .856	P= .232
LOGTSS	0.0167	-0.1028	-0.2563	0.1476	0.3224	-0.2183	-0.3224
	P= .943	P= .657	P= .262	P= .523	P= .154	P= .342	P= .154
DO	0.3969	0.1086	-0.1173	-0.2745	-0.2243	-0.237	0.2243
	P= .075	P= .639	P= .613	P= .228	P= .328	P= .301	P= .328
LOGBOD	-0.0238	0.1918	0.1528	0.3741	0.3949	0.07	-0.3949
	P= .918	P= .405	P= .508	P= .095	P= .076	P= .763	P= .076

Conclusion and discussion

(1) The influence of sampling methods

Two sampling methods gave quite different snapshots of the local benthic fauna. Reasons for this include the fact that they sampled different parts of the local stream environment, and inherent bias towards certain taxa related to the differential efficiency of the methods. Clearly, qualitative edge-water sampling using a pond-net cannot replace the conventional quantitative method in any rapid assessment protocol which depends on reference data generated by the latter method.

The use of a pond-net or hand-net to sample macroinvertebrate fauna can be effective for certain purposes and is recommended elsewhere (e.g. Furse *et al.* 1981, De Pauw and Vanhooren 1983, Wright *et al.* 1988, Hellawell 1986, Lenat 1988, Abel 1989). It can be an integral component of some rapid bioassessment approaches (Resh and Jackson 1993, Resh 1995). However, my study found that the species composition of qualitative samples is very different from that revealed by the quantitative samples (Table 4.1) and therefore should not be used as a surrogate for the latter. It is noteworthy that the qualitative from edge waters also failed to show worthwhile correlation with any water environmental variables (Table 4.2). Thus, the opportunity to save time and costs by using edge-water sampling to determine water quality was not possible in this catchment.

(2) Richness measures

Conventional indices using taxon richness measures were effective in this study. However, the results showed that such measures should be derived from quantitative sampling. Almost all the major water pollution variables in this study were correlated to these quantitative richness indices. Thus, using taxa richness in this study clearly indicated the magnitude of water pollution in that the more polluted the waters are, the lower the benthic taxa richness found.

It was noteworthy that when relating benthic family level richness to water quality variables, the correlation values were similar those when using species richness (see Tables 4.2 and 4.3). Therefore, it is concluded that family level identification to quantify water pollution in the Pong river catchment is satisfactory for the purpose.

(3) EPT indices

The Ephemeroptera, Plecoptera and Trichoptera (EPT) index which is widely used in North America also revealed significant differences between sampling methods and local habitats. EPT specimens from edge-water samples had fewer sensitive taxa. Most were Baetidae (Table 4.4), generally known as a widespread family which tolerates a wide range of water pollution (Hellawell 1986). In contrast, EPT species richness from streambed samples was strongly negatively correlated to BOD (r=-0.77), which is the critical water quality problem in this region. Thus, EPT richness from edge-water samples did not reflect any variation in water pollution parameters, while the EPT richness from riverbed samples did, and can possibly save cost and time by not having to include other taxa groups.

Further, the study found that EPT richness also reflects DO levels and therefore has the advantage that it helps identify healthy aquatic ecosystems with well oxygenated waters. However, high DO content does not universally indicate clean waters since it can result from blue green algae blooms which occur frequently in the lower reaches of the Pong river. Streambed samples from highly eutrophic sites typically had zero EPT richness. Consequently, the use of chemical measures alone (e.g. DO) is not appropriate in the Pong whereas biological measures can play a key role in detecting water impacts.

The term EPT is not entirely suitable in this catchment. Stonefly (P) taxa are generally rare in this region (e.g. only three *Phanoperla* were found in streambed samples from site P03). Thus an ET index, rather than EPT, may be more appropriate given the widespread distribution of Ephemeroptera and Trichoptera in this region.

Allied indices are (i) EPT family richness and (ii) percent EPT abundance/total abundance (composition metric). These two indices are widely used in some states of the USA (e.g. Ohio, Oregon, Idaho and Washington, Barbour *et al.* 1995). However, this study found that their correlation to water quality variables is considerably inferior to the full EPT species richness measure.

Given that benthic macroinvertebrate taxonomy, particularly of larval stages, is poor in this region, the use of EPT family level data in detecting organic water pollution is arguably the most appropriate option for this catchment.

(4) Biotic score systems

The score systems principally use only key benthic families existing at a site for classifying water quality condition. All three score systems examined by this study performed similarly well in relation to water pollution. Only benthic families collected from the streambed contributed meaningful results in relation to water quality,whereas those from edge-water samples showed no significant correlation to any water quality variables.

The BMWP/ASPT score was related to DO, BOD and PO_4. BOD and PO_4 are critical water quality pollutants in this catchment, particularly where the river receives high sewage discharges, resulting in very low BMPW/ASPT scores for these river stretches. The results found in this study are broadly the same as reported elsewhere which show that BMWP/ASPT is sensitive to organic pollution (Murphy 1978, Bargos *et al.* 1990, Rossaro and Pietrangelo 1993). Another advantage of this score system is that most of the benthic families listed in BMWP are found in Thailand. This is in contrast to some other systems such as the Chutter score, Trent Biotic Index and Saprobien Index, which utilise a number of taxa which are restricted to particular geographical areas.

It may be a problem that the BMWP/ASPT utilises family scores based on their tolerance values derived from experience in Great Britain, but to a considerable extent these values can be extrapolated to the tropical Pong waters. In general, the present study found that the low-score families listed in BMWP (i.e. highly tolerant) also existed in polluted areas in this region, while the high-score taxa (less tolerant) were found mostly in minimally impacted sites.

Further, correlating these scores to water quality variables in this study, reveals a lot about ecological phenomena in such sites. Resh and Jackson (1993) cautioned that this score may need modification for use in different geographical areas. This study suggests that only slight adjustment may be required to apply this BMWP family scores system for assessing water quality in the Pong catchment.

The SIGNAL which was recently developed by Chessman (1995), yielded a similar result to the BMWP/ASPT system. Indeed, the SIGNAL score system was principally modified from the BMWP, for particular application in Australia. However, SIGNAL only significantly related to two variables, BOD and PO_4, and was less reliable in detecting the most significant water quality variable DO. It seems that SIGNAL is still in a preliminary stage of development and needs wider testing to calibrate the scores.

There are at least two reasons why the SIGNAL results differ somewhat from the BMWP/ASPT. One reason is that SIGNAL adds some additional families to the BMWP/ASPT lists, e.g. Ceratopogonidae, Protoneuridae, Thaumaleidae, Tasimiidae and Veliidae. Secondly, it may be that SIGNAL changed some former families' scores in BMWP, e.g. Baetidae, Gomphidae and Polycentropodidae. Nevertheless, this study found that SIGNAL is capable of differentiating organically impacted sites in a similar way to the recent study of Growns *et al.* (1995).

Unlike the previous two scores, the Hilsenhoff's scoring system performed poorly in detecting organic pollution, showing no significant correlation with BOD for example. However, this score system has high sensitivity to nutrient levels (NO_3 and PO_4). Hilsenhoff's scores consider only the arthropod fauna while excluding other taxa. Also, some of its allocated scores are rather different from those in BMWP/ASPT, e.g. the family Heptageniidae in BMWP/ASPT is accorded the highest sensitivity score of 10, but in Hilsenhoff's system is designated "moderately sensitive" at 4 (Metcalfe 1989, Hilsenhoff 1988). The latter system failed to discriminate between impact and less impact sites in the Pong catchment, while both BMPW/ASPT and SIGNAL did so satisfactorily.

Hilsenhoff's biotic index is one of the widely used indices in the USA, but Hilsenhoff (1988) himself recognised that his index had limited capacity and was not intended to replace the biotic indices (BI).

(5) Diversity indices

Of the four diversity indices applied, only the Shannon Weiner index yielded satisfactory results and its value successfully correlates to DO and BOD. Simpson's and Hurlbert's PIE indices both showed significant correlation only with DO levels. Margalef's indices, on the other hand, did not reveal significant association with any water quality variables.

These indices, when based om data from qualitative sampling, yielded no correlation with water quality variables. Strictly speaking, these indices require quantitative data, but what I tried to test is whether the time-standardised pond-net samples can be viewed as yielding a semi-quantitative type of data and therefore transformed to diversity indices. Nevertheless, all four diversity indices failed to clearly reflect any changes in water quality variables.

Only H' performed well in relation to changes in water quality when using streambed samples. In fact, the fluctuation of H' values was well correlated with BMWP species richness (r=0.71) and BMWP/ASPT (r=0.67). H' requires species level identification while the BMWP score system only requires family level. Therefore in a practical sense, the BMWP is more advantageous (faster) than H' when one wants to monitor water pollution rapidly.

In general, healthy aquatic ecosystems tend to have high community diversity (Spellerberg 1992). Despite the critique of diversity indices by Washington (1984), published testing of the performance of various indices is scarce. In this study I do not make any further judgement about particular formulae, but look at the performance of each index alone by relating it to what is occurring in the Pong river waters. However, whereas Washington (1984) found that only Simpson's (D) and Hurlbert's PIE were adequate for aquatic ecosystem assessment, my study found that these two indices failed to adequately reflect water pollution in the Pong catchment.

In summary, the assessment of water quality in the Pong catchment by means of indices and scores derived from the macroinvertebrate fauna is quite promising. Data from qualitative sampling of edge-waters along the river bank was reliable in relation to water pollution quantification, while the quantitative did respond to water quality changes. Richness measures, both at species and family levels, were superior to other indices and scores in assessing water quality. EPT richness measures are also valid in a similar way to taxa richness. The BMWP/ASPT score system was more reliable in detecting organic pollution while other scoring methods performed poorly. Of the four diversity indices tested, the Shannon Weiner index (H') was the most sensitive to variation in water quality.

CHAPTER 5

Water Quality Impact Assessment: A Comparative Analysis Using Different Taxonomic Resolution with Abundance and Binary Data

Introduction

The results from Chapters 3 and 4 demonstrate the utility of the macroinvertebrate fauna in reflecting water quality changes in the Pong catchment. All the analyses employed so far in this study have used taxonomic resolution mostly at the level of genus and species, although ordination of a binary dataset (i.e. presence/absence) was used in Chapter to confirm the TWINSPAN analysis. However, experience shows that identification to this level is extremely time consuming. Generally speaking, it is preferable to identify each individual to species level in order to maximise the likelihood of detecting small scale changes in water quality. However, such resolution is rarely possible and in most cases the currently available keys are only to family level (Resh 1995).

Most keys to benthic macroinvertebrate larvae have been recently developed in each region or been revised. Examples include the mayfly larval keys for the British Isles by Elliott *et al.* (1988), case caddisfly larval keys by Wallace *et al.* (1990), all major aquatic groups in the USA by Merritt and Cummins (1984) and for China by Morse *et al.* (1994). These keys cannot be used universally and additional work remains to be done to develop more regionally focussed keys and ecological summaries, particularly for tropical Asia. Research into benthic larval taxonomy, and related environmental factors which affect the occurrence of these groups has received only minor attention so far in southeast Asia.

The use of macroinvertebrates for monitoring water quality generally requires the identification of mixed faunal groups rather than a single taxon. Therefore, this approach depends on accessible, competent taxonomists expertise on each taxon group. Consequently, the identification tasks will normally require more time to complete if numerous taxa are collected. Also, identification work is often "slower" than the analysis and interpretation of data, particularly in biological water quality impact studies. Practically, as I have been involved in water quality assessment for more than ten years, I also recognise that water quality managers generally cannot "wait" for such reports. They often complain that the use of biological methods is very "time consuming" and expensive as also noted by Norris and Norris (1995).

The key question therefore is, how can we reduce the time and labour costs in obtaining the raw data? If quantitative sampling is desired as a standard, is there any alternative other than to have to identify all of the specimens collected, sometimes in enormous numbers? (more than 5000 organisms were collected at each sampling occasion in this study).

The results from Chapter 3 confirm that the best sampling time for detecting human impacts in this part of Asia is during dry season. This is the time when natural confounding effects are less pervasive and when human impacts are more significant. Thus the question can be posed: is there any difference in the results between annual and seasonal sampling data regimes? To approach the goal of so-called "rapid assessment" can we use simply the presence and absence of species (binary data) or is resolution at family appropriate? Or indeed, can binary data at family level still generate treliable results? This Chapter attempts to answer all of these questions.

Aims of study

The precise questions addressed in this Chapter are: (1) can the presence and absence of benthic fauna at genus or species level reveal similar pattern to that of species or genus abundance; (2) does abundance at family level show the same pattern as that of species level? (3) is binary data at family level, also reliable?, and (4) can the dry season dataset alone predict most of the outcomes generated from the full year dataset? If one of these alternatives appears to be effective, this will enable its future use in assessing water quality in this catchment, with beneficial time and cost savings.

Methods

Analysis was undertaken on two data sets: year-round and dry season data. All quantitative samples from the Pong catchment over two years (1995-1996) were combined, to generate an annualised data set. The sampling data from December, February and April 1995, is designated as the "dry season data set". As all faunal data was unimodal and somewhat noisy in nature, the raw density data was transformed to log (x+1) prior to statistical analysis (Elliot 1978). Water quality variables for which correlation to faunal data sets was sought, were tested for normality in distribution (Kolmogorov-Smirnov Test). Those not conforming to normality were log (x) transformed.

The software program used for multivariate analyses was the PATN package (Belbin 1995). The ordination of sites used HMDS (SSH option in PATN), a robust ordination method which has proved to be effective in aquatic invertebrate studies elsewhere (Marchant 1990). The Bray-Curtis (Czekanowski) association measure was used throughout. The co-ordinated from the 2-dimension HMDS solution were plotted, and the corresponding stress levels are quoted in the figure captions. And as a parallel, the ordination analysis was confirmed by a clustering method using UPGMA (FUSE option in PATN). Groupings of the sites produced by FUSE were assisted by the cases groupings option in PATN (GDEF option). Four-site groupings from the GDEF option were chosen, so as to compare between the results of each data set. The validity of GDEF site groupings was also tested by Clark 's ANOSIM (analysis of similarity) (ASIM option in PATN).

Annual data analyses

The sequence of steps in the annual data analysis was as follows: Firstly, the data were separated and analysed according to taxa abundance (density) at genus or species level. The ordination generated from this data set was proposed to be the control model to be compared with the subsequent analyses from less taxonomically resolved data. Secondly, the same set of data was organised into presence and absence at genus or species level. Thirdly, analyses were made only on family abundance data (density). Lastly, the data set was analysed by extracting only presence and absence of faunal families. All these data sets used HMDS for ordination and UPGMA for sites clustering.

Dry season data analyses

The dry season data set was analysed in the same manner as the annual data set.

Correlation between each faunal data set with water quality data used discriminant function analysis (DFA) in SPSS (1994) (Green 1993, Wright 1995). The grouped site-members assigned by the UPGMA were entered into the DFA, then water quality variables were chosen to predict the group memberships. The DFA method applies water quality variable data alone to explore the most significant water quality discriminators between UPGMA site groupings, via canonical discriminant functions. The DFA function was then tested against Wilks' Lambda with only DFA functions at $P<0.05$ being retained. The water quality values used in this Chapter were the same sets as those analysed in Chapter 3.

Results

Species level: abundance versus presence and absence data

Ordination of sites using annual genus or species density (abundance) and binary data, appeared to generate the same pattern (Figs.5.1a, 5.1b). Only slight distortion of sites P04 and P09 in the ordination space was apparent between the two outputs.

This similarity was also confirmed by the UPGMA analyses, where the sites using both species abundance and binary data were clustered into exactly the same groups and membership content (Table 5.1). This surprising result suggests that using only binary data from quantitative benthic species samples is still very effective, largely providing the same outcome as when the full species abundance (density) data were used.

The density and binary data results (Figs. 5.1a, 5.1b), both include the less impacted sites downstream, P11, P12 and P14, into the less disturbed region. The ordination on binary data also isolated the discrete polluted sites, P15 and P16, in a similar manner to the full abundance data set, and this outcome is a useful cross check between results from the two data types.

The most significant water quality variables which explained the separation between UPGMA site groupings were BOD, NO_3, PO_4 and DO. These three variables are highly related to function 1 of the DFA (Table 5.2). Alkalinity, TSS and depth, to a lesser extent, were also important factors which contributed to the discrimination among UPGMA site groupings. However, these latter variables are relatively less significant and associate with function 2 which accounted only for 25.35% of the variance explained. This suggests that the site arrangement in the ordination space was largely influenced by organic pollution. In other words, the abundance (Figs. 5.1a) and presence and absence of benthic fauna (Fig.5.1b) in this catchment is mostly affected by organic sources (BOD) and nutrients (NO_3 and PO_4).

The profile of water quality values for various UPGMA site groupings is shown in detail in Table 5.3. The upper catchment sites had relatively higher TSS and alkalinity levels, but less organic pollution. The results suggest that the high levels of TSS (mainly caused by siltation) and alkalinity in upstream sites had a relatively minor effect on benthic fauna assemblages when compared to organic pollutants.

The notations "less-impact' and "impact" sites as in Figs.5.1a and 5.1b and thereafter will mean the relatively less and more impacted sites as measured by their organic pollution levels.

The impact of organic pollution is very obvious in sites P15 and P16, which have very few benthic animals year-round under conditions of high BOD levels and nutrients. These two sites are well isolated from the others in the ordination space. This implies that high organic pollution loads are measured well by the benthic community, and supports the robustness of macroinvertebrate data in detecting organic pollution even when scoring only the presence and absence of species at a site (Fig.5.1b).

Table 5.1 Site groupings produced from UPGMA when using benthic density and binary data at species level

UPGMA site groupings	Sites
1	P01, P02, P03, P04
2	P11, P12, P14
3	P05, P06, P07, P08, P09, P10, P13, P17, P18, P19, P20, P21
4	P15, P16

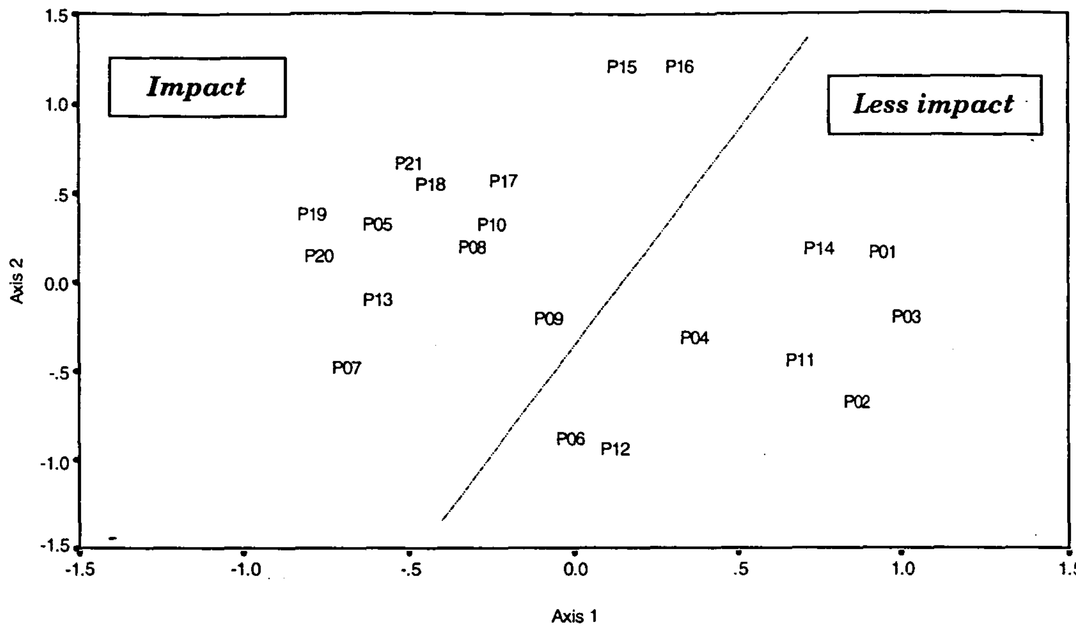
Table 5.2 Pooled within-groups correlations between discriminating variables and canonical discriminant functions from UPGMA grouped sites using species density and binary data

(Only functions 1, and 2 are significant when tested against Wilks' Lambda, P=0.0001 and P=0.0086, respectively, with 100% grouped cases classified)

Water physicochemical variables	Function 1	Function 2
BOD	0.75188*	-0.11379
NO_3	0.49168*	-0.00855
PO_4	0.48583*	-0.10009
DO	-0.28829*	0.21420
Alkalinity	0.09485	0.46313*
TSS	-0.01591	0.45409*
Water temperature	0.01278	-0.17959
Depth	-0.11400	-0.25471*
Discharge	-0.13202	-0.21342
pH	-0.07280	0.04348
EC	0.07994	-0.06673
Canonical correlation	**0.9703**	**0.9271**
Percent variance explained	**66.53**	**25.35**

**denotes absolute largest correlation between variables and functions*

(a)



(b)

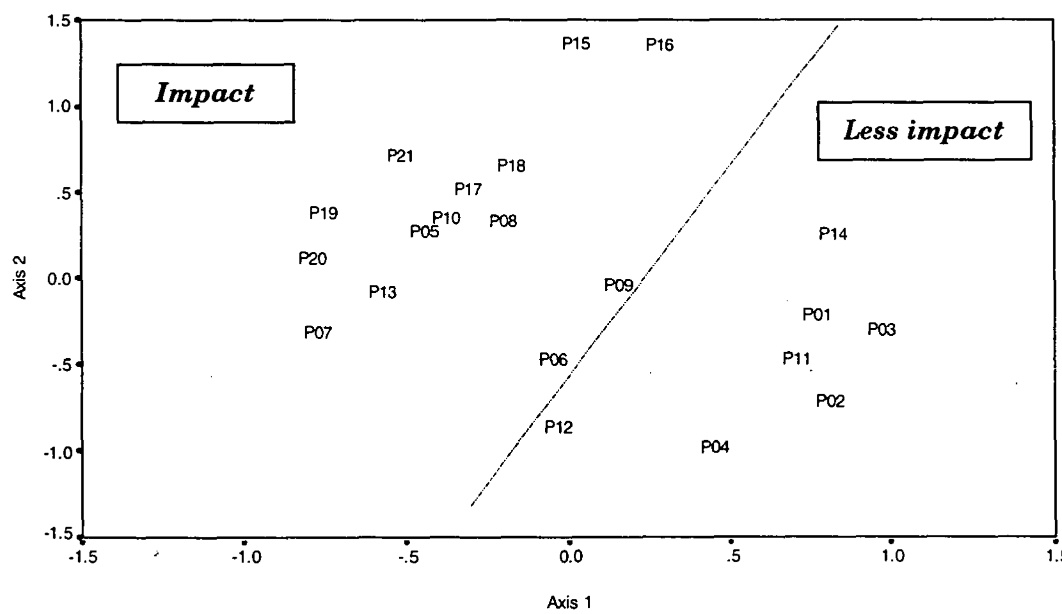


Figure 5.1 Sites ordination using (a) species or generic density data (stress 0.1501), and (b) species binary data (stress 0.1305).

(dotted line represents the impact and less-impact zones and this will be used thereafter as a rough organic water pollution reference line)

Table 5.3 Major water quality values (mean±SD) between UPGMA site groupings

Water physicochemical variables	**UPGMA site groupings**			
	1	**2**	**3**	**4**
BOD	2.59±2.49	2.8±32.64	3.8±2.18	10.29±7.59
NO_3	0.54±0.66	0.46±0.38	0.65±0.51	1.45±1.05
PO_4	0.09±013	0.06±0.17	0.16±0.12	0.34±0.38
DO	7.16±1.52	6.43±2.85	5.8±1.7	3.49±2.41
Alkalinity	133.28±53.58	89.03±12.61	96.70±30.00	112.85±27.80
TSS	202.49±93.30	18.30±21.19	43.45±60.56	36.04±23.57
Depth	0.41±0.32	1.80±1.80	4.61±2.93	1.53±0.81

Family level: abundance versus presence and absence data

Resolution at family level induced some distortions in site positioning in the ordination space. The sites grouped by UPGMA on family data are rather different from that based on species level data (compare Tables 5.1 and 5.4). Both density and binary data types produced slightly different group membership by UPGMA except for site groupings 1 and 2 (Table 5.4).

As both density and binary family data generate the same membership in UPGMA site grouping 1, these two data types cannot discriminate among the less impacted sites unlike the species level data (Tables 5.1 and 5.4). Apart from this, there are still some major differences between results using species versus family data.

Firstly, site P06 classifies into the less impacted region when using family density data set. Interestingly, this site is in the "marginal" boundary as shown in Figs.5.1a and 5.1b. Therefore, when using family density data fine scale discrimination between some sites cannot be achieved. This is similar to what occurred in the case of site P07, as UPGMA analysis on density data cannot group this site into any cluster (Table 5.4).

Secondly, both density and binary species data effectively discriminated "minimal impacted sites" (i.e. P01-P04), from other sites, while both family data types cannot. Instead, the two family data types add some more items (P06, P11, P12 and P14) to these sites (see comparative UPGMA site grouping 1 in Tables 5.1 and 5.4).

Lastly, each family data set produced different site memberships in UPGMA site groupings 1 and 2 (Table 5.4). In contrast, density and binary data at species level generate similar site memberships in each UPGMA site grouping (Table 5.1).

However, to a certain extent, the cluster using both family data types was still effective in identifying the highly organic impacted sites (P15 and P16) (Table 5.4). Also, a feature of the family level data more generally, is that each family data type generates similar memberships in UPGMA site grouping 1, whose members may be classified as "less impact" sites in reference to the full species data (Figs.5.1a, 5.1b).

When using family level data, the site arrangement in the ordination space was somewhat different (less resolved) from the reference model (compare Figs.5.1a, 5.1b and 5.2a, 5.2b). Without the aid of UPGMA results, the site groupings in the ordination space of family data are poorly discriminated, and only approximate impact and less disturbed zones can be nominated.

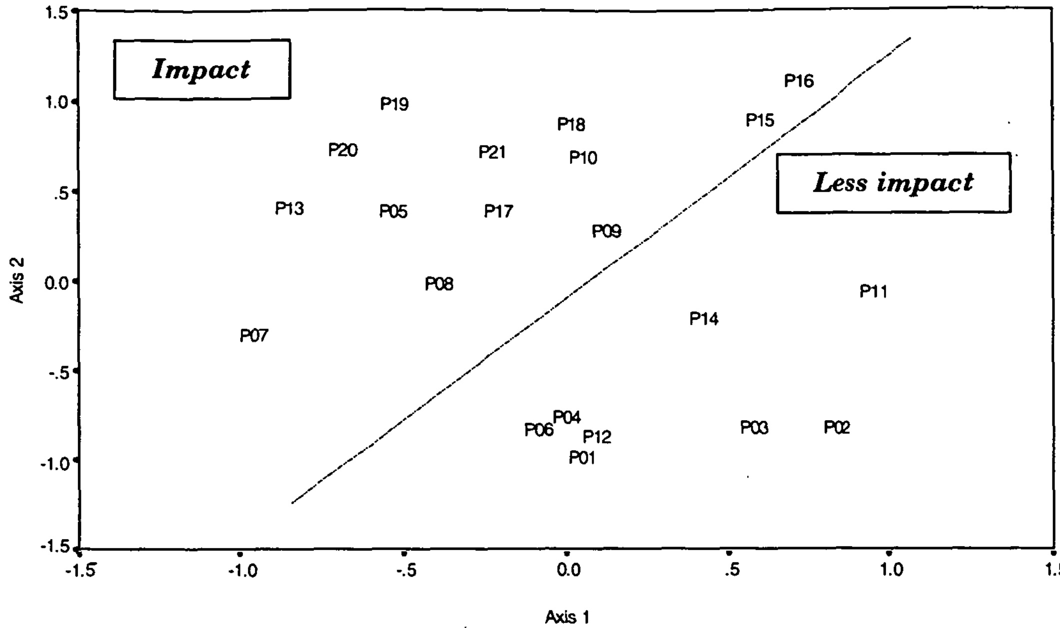
When correlating water physicochemical variables with UPGMA grouped sites on family level data, BOD, nutrients (PO_4 and NO_3) and DO are also significant discriminators (Table 5.5). However, this is only true for family density data, but not for binary data. The major water physicochemical variables which explain the separation of the UPGMA site groupings of binary data are different from those using density data, which in fact, correlate to the physical factors, i.e., depth and discharge, rather than organic pollutants (Table 5.6). Therefore, the UPGMA analysis using family binary data discriminated the sites with high discharge (P09 and P10), from the others (UPGMA site groupings 2 in Table 5.4). These two sites are located below the large dam.

In conclusion, it appears that family binary data gives less reliable results compared to species or family density data. The benefit of using binary family data is to identify the impact and less impact zones, but details of the causes will be less apparent as confirmed by DFA analysis.

Table 5.4 Site groupings produced from UPGMA when using (a) density, and (b) binary family data

UPGMA site groups	a	b
1	P01, P02, P03, P04, P06, P11, P12, P14	P01, P02, P03, P04, P06, P11, P12, P14
2	P07	P09, P10
3	P05, P08, P09, P10, P13, P17, P18, P19, P20, P21	P07, P05, P08, P13, P17, P18, P19, P20, P21
4	P15, P16	P15, P16

(a)



(b)

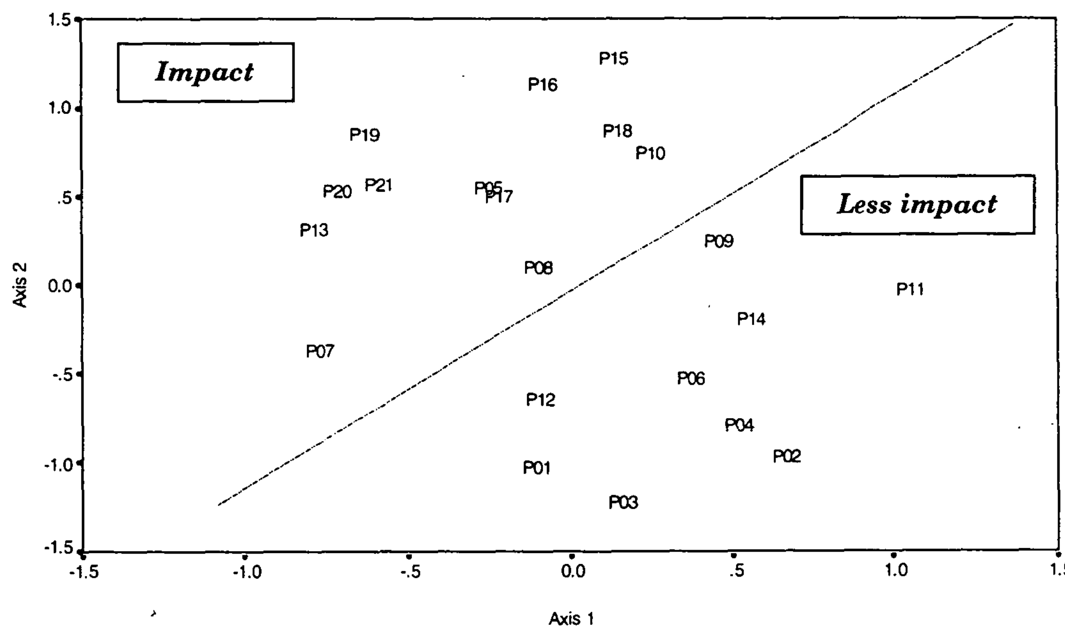


Figure 5.2 Sites ordination results using (a) density (stress 0.1287), and (b) binary family data (stress 0.0981)

Table 5.5 Pooled within-groups correlations between discriminating variables and canonical discriminant functions from UPGMA grouped sites using family density data

(Only functions 1, and 2 are significant when tested against Wilks' Lambda, P=0.0002 and P=0.0266, respectively, with 100% grouped cases classified)

Water physicochemistry variables	Function 1	Function 2
BOD	0.79991*	0.05606
PO_4	0.49723*	0.02957
NO_3	0.48908*	-0.04192
DO	-0.29041*	-0.19920
Depth	-0.15041	0.53736*
Discharge	-0.16752	0.45816*
Alkalinity	0.05539	-0.19507
TSS	-0.02436	-0.15482
EC	0.07782	0.14104
Water temperature	0.01889	0.27970*
pH	-0.08693	0.09675
Canonical correlation	**0.9704**	**0.9355**
Percent variance explained	**67.16**	**29.16**

** denotes largest absolute correlation between each variable and discriminant functions*

Table 5.6 Pooled within-groups correlations between discriminating variables and canonical discriminant functions from UPGMA grouped sites using family binary data

(Only functions 1 is significant when tested against Wilks' Lambda, P=0.0058, while function2 P=0.2588, with 100% grouped cases classified)

Water physicochemical variables	Function 1	Function 2
Depth	0.55239*	0.07856
Discharge	0.30607*	0.10037
Alkalinity	-0.13691*	-0.08877
Water temperature	0.03707	0.42794*
EC	0.00885	0.35154*
pH	0.02401	0.30168*
DO	-0.08927	-0.05439
BOD	-0.02471	0.08098
PO_4	-0.00368	0.15315
NO_3	-0.05528	0.15815
TSS	-0.11768	-0.08678
Canonical correlation	**0.9649**	**0.8155**
Percent variance explained	**80.82**	**11.89**

** denotes largest absolute correlation between each variable and discriminant functions*

Dry season analyses

Species level data

Species abundance (density) and binary data analysed by UPGMA both produced the same site groupings (Table 5.7), which resemble the outcome when the full annual data set was used (Table 5.1). One exception is site P06; analysis of the dry season data set clusters this site into the minimal disturbed sites (P01 to P04). Indeed, allocation of site P06 was problematic on the basis of both UPGMA and HMDS analyses. Clustering of the annual species data set clearly excludes this site from the less disturbed group sites, whereas the UPGMA annual family data set includes it with the less disturbed sites. Nevertheless, analysis of the species density data from the dry season alone strongly reflects the results obtained when the full annual species data set was used.

Similarly, the two ordinations of dry season data (Figs.5.3a, 5.3b), both feature relatively clear discrimination between sites. The less disturbed sites, P01 to P06, in particular, are well separated from the impacted sites. Several related sites P11, P12 and P14, (UPGMA site grouping 2) represent on "intermediate zone" between less disturbed and impacted sites. These three sites are clearly identified by density or binary data in the ordination space (Figs. 5.3a, 5.3b). Thus, the binary data at species or genus level looked promising in detecting water impacts occurring in the dry season.

As for the annual data set, the water physicochemical variables which best explain the cluster groupings in the dry season are organic pollutants (Tables 5.2 and 5.8). DFA function 1 is highly correlated with PO_4, BOD, NO_3 and DO, respectively. Whereas the annual species data grouped sites highly correlated with BOD, in the dry season the species data are most significantly related to the level of PO_4. Within the Pong catchment during summer, markedly high PO_4 levels occur in sites close to Khon Kaen city, such as site P16 with the highest levels of PO_4 (0.65 mg/L) and BOD (15.19 mg/L). This site was well isolated from the others in the ordination plot (Fig.5.3a). This result suggests that the PO_4 discharged by the community in summer could have a very significant effect on benthic species (Table 5.8).

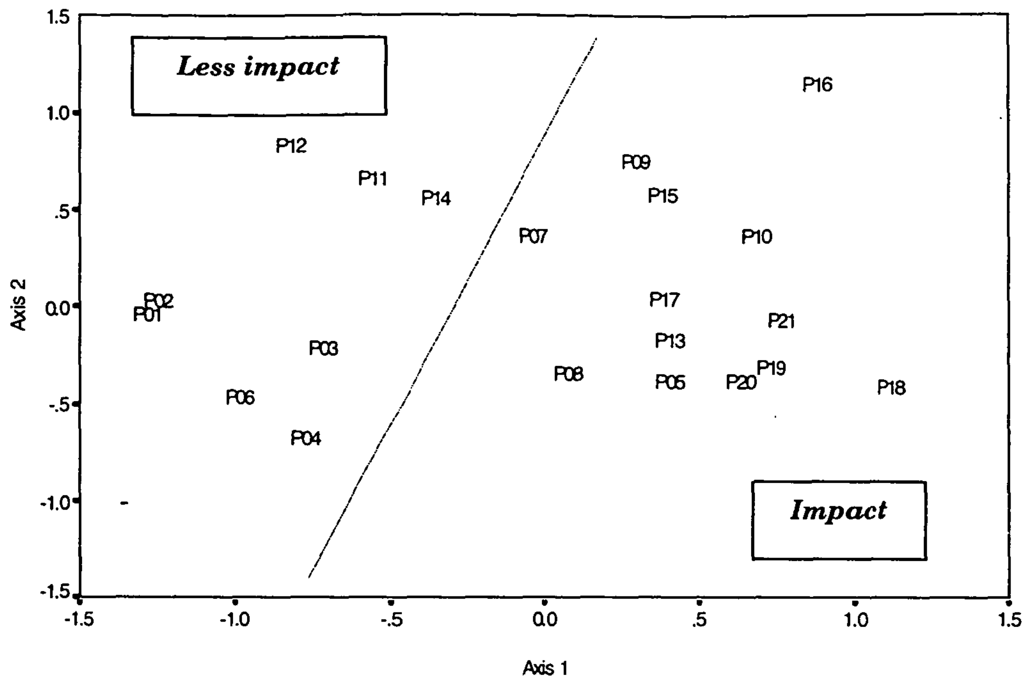
In the dry season, PO_4 also enters the river from agricultural lands. This can be observed in sites P07 and P08, which are located below site P06, but they both have relatively high PO4 levels (0.19 and 0.18 mg/L respectively). As a result, during the dry season these two sites are classified in the impacted zone (Figs.5.3a, 5.3b).

The results from site ordination clearly confirm the possibility and advantage of using benthic fauna as an indication of water pollution. At a gross scale the impacted and less disturbed zones are quite discrete in the ordination space (Figs.5.3a, 5.3b), but within each zone finer discrimination between sites is less clear. Fuller interpretation of these data therefore require input from analysis by both clustering and ordination methods.

Table 5.7 Site groupings produced from UPGMA when using density and binary species data

UPGMA site groups	Sites
1	P01, P02, P03, P04, P06
2	P11, P12, P14
3	P05, P07, P08, P09, P10, P13, P17, P18, P19, P20, P21
4	P15, P16

(a)



(b)

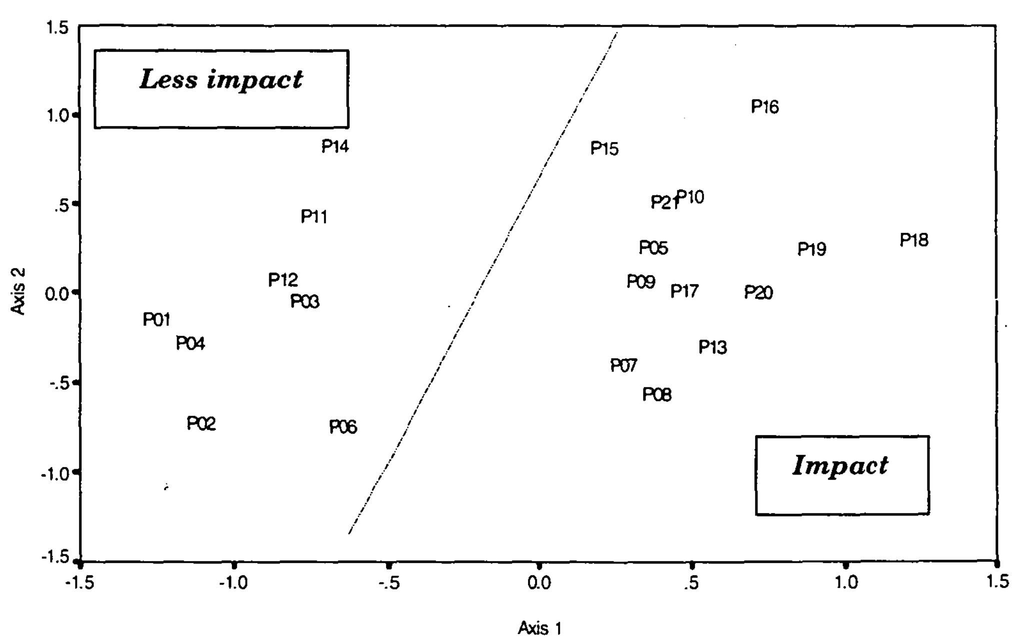


Figure 5.3 Site ordination in dry season using (a) density (stress 0.1400), and (b) binary species data (stress 0.1174)

Table 5.8 Pooled within-groups correlations between discriminating variables and canonical discriminant functions from UPGMA grouped sites using density and binary species data

(Functions 1 and 2 are significant when tested against Wilks' Lambda P=0.0001 and P=0.0106, respectively, with 95.24% grouped cases correctly classified)

Water physicochemical variables	Function 1	Function 2
PO_4	0.47598*	0.15555
BOD	0.33370*	-0.00538
DO	-0.11915*	-0.07572
Depth	-0.08611	0.50915*
Discharge	-0.07052	0.32697*
pH	-0.0716	0.20330*
NO_3	0.12543*	-0.16866*
Alkalinity	0.02118	-0.12083
TSS	-0.00575	-0.13573
Water temperature	-0.00392	-0.02151
EC	0.02085	0.08506
Canonical correlation	**0.9890**	**0.9366**
Percent variance explained	**83.90**	**13.40**

** denotes largest absolute correlation between each variable and discriminant functions*

Family level data

Ordination of sites using family level density and binary data have almost the same pattern (Figs.5.4a, 5.4b). However, the sites in the ordination space are relatively more discrete in response to water quality gradient when using density data as the input.

Clustering (UPGMA) the sites using both data sets separately produces somewhat different groupings (Table 5.9). Only site grouping 1 from both data sets has similar membership and both analyses failed to finely discriminate between less polluted sites. This problem also was evident when annual family data sets were used. However, the family density data still identify the outlier sites (P15 and P16), similar to when the species data set were used.

The binary family data resolves only the broad dichotomy of impact and less impact zones. Its detailed separation between each grouped site is less useful when relative to the family density data (compare UPGMA site grouping memberships in Table 5.9). Further evidence comes from site P15 which the family binary data separated from site P16, while all of the species and family density analyses group this site with P16.

(a)

(b)

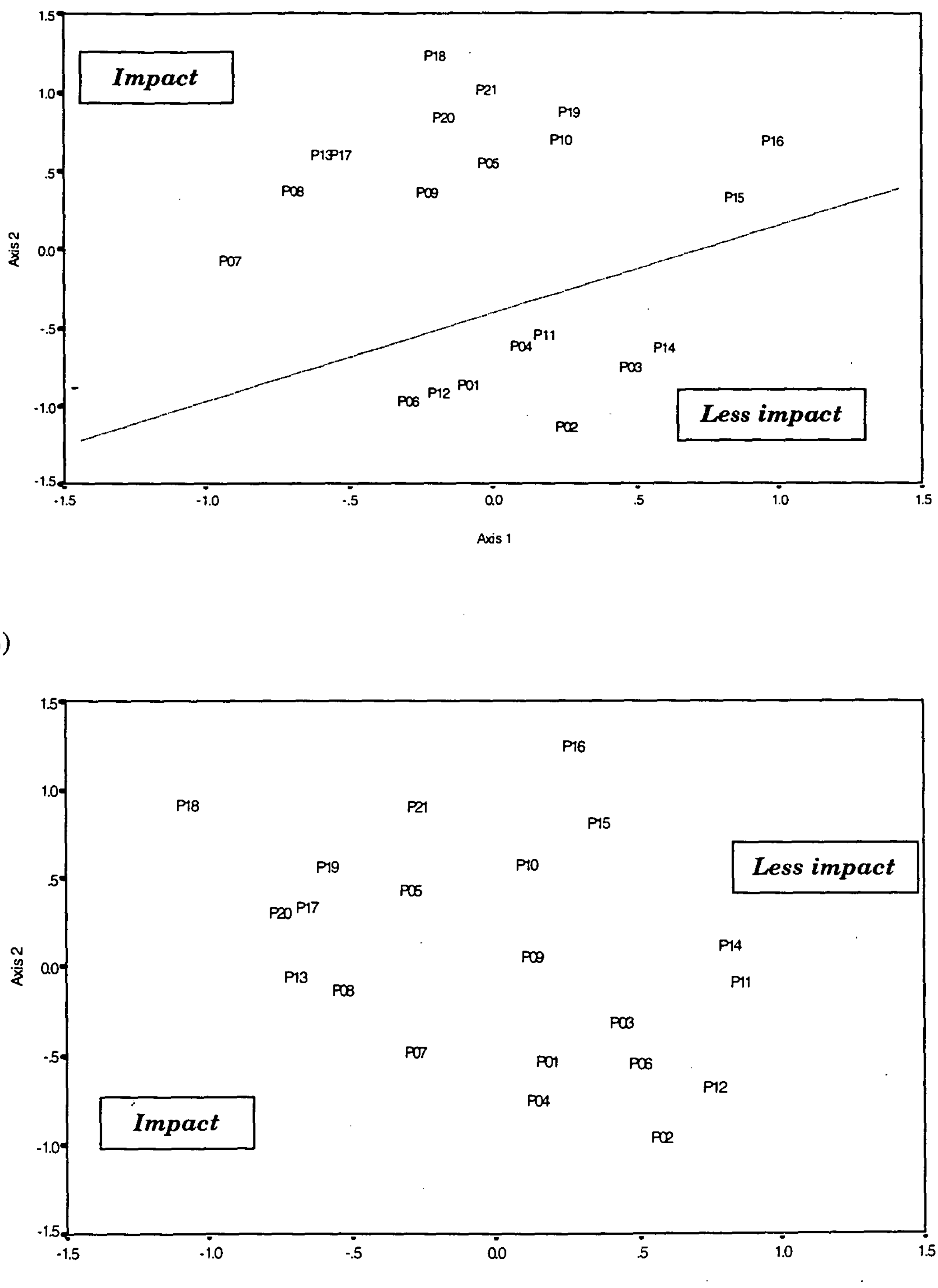


Figure 5.4 Sites ordination using (a) density (stress 0.1188), and (b) binary family data (stress 0.1013)

Table 5.9 Site groupings produced by UPGMA when using (a) density, and (b) binary data at family level

UPGMA site groups	**a**	**b**
1	P01, P02, P03, P04, P06, P11, P12, P14	P01, P02, P03, P04, P06, P11, P12, P14
2	P07, P08, P09, P13, P17	P09, P10, P15
3	P05, P10, P18, P19, P20, P21	P07, P05, P08, P13, P17, P18, P19, P20, P21
4	P15, P16	P16

Family density data is still reliable when examining spatial community structure in relation to water quality variation. Table 5.10 summarises DFA results which identify organic pollutants as being major discriminators between UPGMA site groupings. This is similar to what was found when using species level data (compare Tables 5.8 and 5.10).

In the case of family binary data, however, the DFA cannot clearly explain which water quality variables are influencing the separation between faunal UPGMA site groupings. The major DFA function 1 (85.70% variance explained and P=0.0001) (Table 5.11) fails to relate water quality variables to any UPGMA site groupings. In other words, correlations between water quality variables and the benthic faunal community are less reliable when using family binary data.

Table 5.10 Pooled within-groups correlations between discriminating variables and canonical discriminant functions from UPGMA grouped sites using family density data in dry season

(Functions 1 and 2 are significant when tested against Wilks' Lambda P=0.0001 and P=0.001, respectively, with 100% grouped cases correctly classified)

Water physicochemical variables	Function 1	Function 2
PO_4	0.47373*	0.02136
BOD	0.34655*	0.00211
DO	-0.12007*	-0.02520
Discharge	-0.07875	0.37253*
Depth	-0.07488	0.34112*
pH	-0.06634	0.15878*
Alkalinity	0.01307	-0.08754
NO_3 -	0.13555*	-0.05160
Water temperature	-0.00006	0.07962
EC	0.03028	0.12207
TSS	-0.00813	-0.07472
Canonical correlation	**0.9891**	**0.9743**
Percent variance explained	**68.48**	**28.38**

** denotes largest absolute correlation between each variable and discriminant functions*

Table 5.11 Pooled within-groups correlations between discriminating variables and canonical discriminant functions from UPGMA grouped sites using family binary data in dry season

(Functions 1 and 2 are significant when tested against Wilks' Lambda P=0.0001 and P=0.046, respectively, with 100% grouped cases correctly classified)

Water physicochemical variables	Function 1	Function 2
Alkalinity	0.06996	-0.01315
BOD	-0.00666	0.58184*
PO_4	-0.07130	0.41295*
NO_3	0.0663	0.27614*
pH	-0.03857	-0.12173
DO	0.10921	-0.1743
EC	-0.01153	0.08212
Depth	-0.21854*	0.00133
Discharge	-0.14015	-0.03664
TSS	0.05822	-0.07937
Water temperature	0.01657	0.00494
Canonical correlation	**0.9846**	**0.8804**
Percent variance explained	**85.70**	**9.31**

- *denotes largest absolute correlation between each variable and discriminant functions*

Conclusion and discussion

Species versus family abundance data

The influence of taxonomic resolution in the data to be analysed is very significant as shown by the results of this study. The relationship between sites based on their benthic faunal community, and water quality, is more apparent when using species level data. For less-impacted sites, the species level data can clearly discriminate sites into subgroups, while the family level density data cannot. The least disturbed sites identified from the species level data may be used as reference sites within the region, and can be used to compare with any later test sites (Omernik 1995).

It has been claimed that in order to analyse benthic community structure in relation to water quality, species level identification is almost essential (Resh 1975, Lenat and Barbour 1994). Minor changes in water quality can cause changes in the macroinvertebrate fauna at species level, and the results from this study reinforce this point.

However, a key question which has been unsolved so far is whether we can use the data only at family level to assess water quality in tropical Asia. This study shows that using macroinvertebrate fauna resolution at family level is still valuable, as previously demonstrated in the temperate zone (e.g. Osborne *et al.* 1980, Furse *et al.* 1984). This study also affirms that fauna responses to pollution not only occur on a minor scale (e.g. a few kilometres of upland stream as in Wright *et al.* 1995), but also at a larger scale such as the catchment landscape units.

The use of family level data in assessing environmental impacts is not new and has been tested in North America and United Kingdom. For example, Plafkin *et al* (1989) used this type of data in generalised rapid bioassessment protocols after success from case studies using family level data. Reduction of cost and time (so-called "rapid bioassessment") drives current practises in the United Kingdom, and the use of family level data is a key part of the predictive RIVPACs model and BMWP (Wright 1995).

In other parts of the world, the utility of family level data is still being tested. For example, in Australia, Growns *et al.*(1995) used family level data via the SIGNAL index and found significant correlations to the ordination axes. In a catchment scale study in Victoria, Marchant *et al.* (1995) comparatively analysed quantitative data at family and genus levels and found that family data still contributed valuable information about the classification of spatial sites.

Generally, references utilising family data which deal directly with water quality variation are scarce. The previous studies mostly indirectly analyse the correlations between benthic fauna and water quality variables. The water quality data they obtained are mostly from secondary sources, such as Water Authorities records. Simultaneous and rigorous measurement of water quality and sampling of the macroinvertebrate fauna at the same place is rarely reported. Another constraint is that most studies have been done in relatively mountainous landscapes and exclude polluted river stretches in the lowlands or near cities. Studies that describe designs for evaluating gradients from least disturbed to highly polluted sites on the same catchment plain are scarce. It is only recently that the catchment-wide ecosystem evaluation approach has received significant attention (Johnson and Gage 1997, Richards *et al.* 1997, Townsend 1997).

This study enlightens some of the above points in terms of the intensity of organic water pollution that affects the benthic fauna. In summary, both annual species and family density data analyses gave similar spatial pattern results in relation to the magnitude and distribution of organic pollution. However, the former data set provided finer resolution between the sites in the Pong river catchment. Furthermore, this study contributes to the possibility of time and cost reductions in annual quantitative macroinvertebrate sampling to assess catchment water quality in tropical Asia.

Binary data (presence and absence)

Surprisingly, binary data (presence and absence) at species or generic level gives only slightly different ordination results from that of species abundance data. Further, the sites clustered by UPGMA using either species abundance or binary data, produced the same site groupings. Consequently, it could be suggested that at species level, binary data is still sufficient in recognising water pollution impacts.

Species level binary data has been found effective in studies in the temperate zone and is promoted in standardised protocols in water quality assessment, particularly in the United Kingdom (Wright 1995). This study strongly suggests it may also have application in the assessment of flood-plain waters in tropical Asia where no tests have been conducted previously.

The annual family binary data set was less effective as evident from the ordination and clustering results. However, the sites' pattern in the ordination space still roughly identified the impact and less impacted zones. The UPGMA clustering results using family binary data differed from the results when family density data were applied, although both data types resulted in similar memberships in less impact sites.

The choice of data type is thus between species binary data or family density data since each can be cost-effective in assessing water quality. In the HMDS ordination space, the species data provides more accurate resolution than the latter. Although, the grouped sites clustered by UPGMA from both data sets are somewhat different, the species data set produces a more robust result while the latter signified roughly only the impact and less-impact sites.

In conclusion, if one wants to assess water pollution in this region as a "big picture", i.e. on a catchment-wide scale, then annual family density data analysis is adequate. But to get into a more detailed appreciation of differences between sites, then species binary data is a more appropriate choice.

Dry season data analyses

There is a slight difference between sites in the ordination space when comparing between species density and binary data sets in the dry season. However, the general pattern remains the same. The species density data provides a finer discrimination between sites, which can be classed as least disturbed, moderate, severely impacted and even a self-purification zone. The binary data also gives a similar result to the density data, but with less resolution.

However, both data types yield the same UPGMA site groupings. These grouped sites assist the recognition of zones of impact in the ordination space, i.e. as least disturbed, moderate, severely impacted and self-purification sites. Thus, when using species binary data in assessing water quality in summer, it is necessary to include a clustering method with the ordination analysis. The site associations produced from the two different methods have to be cross-checked with each other then validated by reference to water physicochemical results.

The site groupings based on species data in the dry season are also well correlated to organic water pollution variables. Surprisingly, one measure of inorganic pollutant, conductivity, was found to be less significant in this study than in other studies (e.g. Marchant *et al.* 1995). It could be that in tropical landscapes, the effect of organic pollutants overrides the influence of inorganic impacts. This observation is most apparent in the sites located close to city areas. Typically, the organic pollution intensity along the river length increases where the waters traverse population centres as elsewhere in the tropics (Gopal and Sah 1993).

For dry season family level data sets, both density or binary data produces reasonably different ordination patterns. Like the annual data set, they only indicate approximate limits for the impact and less impacted zones. The first data set provides more a useful result by positioning the most organically impacted sites as outliers, while the latter data indicated such sites poorly.

The classification of sites produced by UPGMA from both data sets was also different. The family binary data gives less reliable site groupings, and the only common feature between the family binary and density data in the dry season is that there is that UPGMA grouped site 1 contains all the less impacted sites. Another difference between them is that the UPGMA grouped sites using family density data showed a marked correlation to organic pollution, while the family binary data related to such pollutants rather poorly.

Overall conclusion

Based on these results, several important conclusions which can be made.

Firstly, both species density and binary data from quantitative sampling contribute robust results by multivariate analysis in relation to water quality impact assessment.

Secondly, family level density data still reflect significant features of organic water pollution, and can be used in general evaluation or rapid assessment of water quality changes on a coarse, catchment-wide scale.

Thirdly, both annual and subset dry season data sets using species density/binary or family density/binary types produce the same outcomes which indicate associations between benthic fauna and water pollution. Cost savings in time and manpower can be achieved by using only species/genus binary data from the dry season while still retaining good accuracy. Thhis protocol should be encouraged in further assessment work in the Pong catchment.

And, lastly, the overall results imply that both HMDS ordination and UPGMA clustering methods based on benthic faunal community can, in combination, successfully evaluate the association of the fauna with particular water quality profiles and impacts. It is also necessary to use both methods together when analysing data, to confirm the arrangement of sites in the ordination space. The HMDS is superior in explaining underlying environmental gradients while the UPGMA is more robust in objectively grouping similar sites, and can correlate such grouped sites with water quality variables via DFA analysis.

CHAPTER 6

Case Study: The Benthic Macroinvertebrate Fauna Assemblage in a Tropical Pine-Oak-Savanna Forest: The Phukradueng National Park, Thailand

Introduction

The Phukradueng National Park occupies a pristine catchment of great ecological value. As Her Royal Thai Princess Sirinthon noted:

> *"The Phukradueng is a large school for everyone who wishes to know what a pristine ecosystem state is like. The Phukradueng can show both features of healthy terrestrial and aquatic ecosystems. It has a unique environment and being more invaluable than mankind can conceive. Let us nurture this piece of land otherwise we will lose more in the future..."*
>
> **Princess Sirinthorn Mahidol**
> Upon a visit to the Phukradueng
> National Park, 1994

The Phukradueng catchment is a unique landscape in northern Thailand, and its highly diverse native flora and fauna remain undisturbed by development and protected by Thai National Environmental Conservation Law.

The local plant communities range from tropical pine-oak-savanna woodland to evergreen forest. The Phukradueng catchment is also an important tropical wildlife refuge, harbouring several thousand animal species including elephant, tiger, deer and monkey.
Several first, second and third order streams run across this landscape, and most have streambeds with a bedrock substratum. All these streams are headwaters which serve the Pong network, the catchment studied in Chapter 3.

The Phukradueng catchment is divided into two main sectors for management: the first is established for eco-tourism purposes and allows the entry of visitors, whereas the second is strictly prohibited to visitors except those who formally obtain permission from the Thai Central government for undertaking environmental study. This study was sanctioned by the Thai Government to investigate the aquatic benthic macroinvertebrate fauna in both open and restricted areas. It is the first study to investigate benthic faunal community and species distribution in this catchment. All sampling operations during field work across the Phukradueng catchment lands with consideration of conservation needs.

Study aims

Five questions were addressed by the macroinvertebrate studies in the Phukradueng catchment:

1. In general, what species of benthic macroinvertebrates, and what communities, are present in the Phukradueng catchment streams?

2. Is there any difference in benthic larvae distribution patterns at various small-scale patches in those pristine streams?

3. Among the various microhabitats at a stream site, which is the most significant in terms of species richness?

4. As there are many different riffle and pool reaches in streams in this catchment, what is the typical benthic community structure in the riffle and pool system?

5. Lastly, what is the nature of the communities associated with various types of organic substrates present at the sites?

The results generated from this study will guide planning for further research into community, population and aquatic species conservation.

Biophysicography of the Phukradueng catchment

The Phukradueng National Park occupies an area of 438 km^2 between 16° 49′-16 59′ N and 101° 41′-101° 50′ E in northeast Thailand. Its landforms create a unique local landscape. A dominating feature is the tilted, plateau-like mountain top, which is an expanse of relatively flat land of about 60 km^2 and the site of this study. The lower margins of the Park lie at an altitude of 260 m.s.l. while the top-most plateau reaches up to 1300 m.s.l. The geology of the Park is mainly sandstone and supports both tropical and temperate plant communities due to the large altitude range.

The vegetation communities of the Park are divided into a lowland zone (200-1000 m.s.l) and a montane zone (1000-1300 m.s.l). The lower communities consist of deciduous dipterocarp forest (DDF), mixed deciduous forest (MDF) and seasonal rain forest (SRF). In the montane zone, the vegetation includes lower montane forest (LMF), lower montane scrub (LMS) and pine-oak savanna (POS).

The climate of the Phukradueng National Park is cooler than the lowlands of the Cheon and Pong catchment, where the temperature ranges from 12-19 °C. In the coolest month of December, the temperature on the mountain top ranges from 0-12 °C. The relative humidity on the top plain is high at 89 percent. The annual rainfall is comparatively high compared to the lower plain with an average of 1228 mm. The soil of the high plain is almost always damp and largely covered by thick grasses and scrub.

On the upper reaches of the plateau, at around 1200 m.s.l, the predominant trees are pines *(Pinus merkusii,* and *P. kesiya)* and oaks *(Quercus acutissima* and *Q. aliena).* Major shrubs growing underneath the trees are *Lyonia ovalifolia, Vaccinium sprengeli, Melastoma normale* and *Ardisia pilosa.* Several grass species grow abundantly over much of the top plateau including *Themeda triandra, Eulalia siamensis, Ischaemum barbatum,* and *Imperata cylindrica.* These grasslands play a prime role in protecting the moisture content of the soil.

The high plateau is tilted to the northwest reaching down to around 1000 m.s.l. where the upper plateau communities are replaced by dense evergreen trees. At this lower altitude, the vegetation becomes very dense and tangled and is a natural refuge for various large tropical animals native to the region. Dominant plant species of this tall evergreen forest are *Acer calcaratum, A. laurinum, Schima wallichii, Dacrydium elatum, Calophyllum polyanthum, Michelia baillonii, Syzygium* sp., *Carpinus viminea, Podocarpus neriifolius, Dacrycarpus imbricatus* and *Castanopsis acuminatissima*.

Sampling site description

This large mountain plateau is a key rainwater catchment for the region and an important origin of headwater streams. These streams run across the high plain from southeast to northwest (Fig.6.1), and finally give rise to a large river, the Pong, which flows across the northeast lowland plain of Thailand.

The pristine streams sampled by this study spanned an altitude range of 300 m, from a high of 1246 m to the lower edge of the high plateau at 940 m.s.l. Sampling sites were in both ecotourist and restricted ("closed") forest lands.

Nine sampling stations were established and were sampled on three occasions. The first grouped sites where located in the pine-oak-savanna community; these are U01 (Fhai Yai), U02 (Wang Kwang), U07 (Pra Ong) and U08 (Tham Sow). The second grouped sites are U03 (Tham Yai), U04 (Pen Pobmai), U05 (Pon Pob), U08 (Pa Nampa) and U09 (Khun Pong), and all their streams are located in healthy evergreen forest. Table 6.1 gives some ecological details of the sampling sites.

Predominant plant species at the first grouped sites are *Pinus merkusii, Anneslea fragrans, Syzygium gratum* and *Schima wallichii*. The distinct plants of the second group are *Acer calcaratum, A. laurinum, Dacrydium elatum, Calophyllum polyanthum, Michelia baillonii* and *Carpinus viminea*.

Table 6.1 Sampling site characteristics, Phukradueng National Park

Site code	Site name	Altitude (m.s.l)	Dominant substrate	Vegetation community
U01	Fhai Yai	1246	Silty clay	Pine-oak-savanna
U02	Wang Kwang	1186	Bedrock	Pine-oak-savanna
U03	Tham Yai	1124	Mixed	Evergreen forest
U04	Pen Pobmai	1155	Bedrock and boulder	Evergreen forest
U05	Pon Pob	1120	Bedrock	Evergreen forest
U06	Pa Nampa	960	Bedrock	Evergreen forest
U07	Pra Ong	1124	Bedrock	Pine-oak-savanna
U08	Tham Sow	1216	Bedrock	Pine-oak-savanna
U09	Khun Pong	940	Bedrock	Evergreen forest

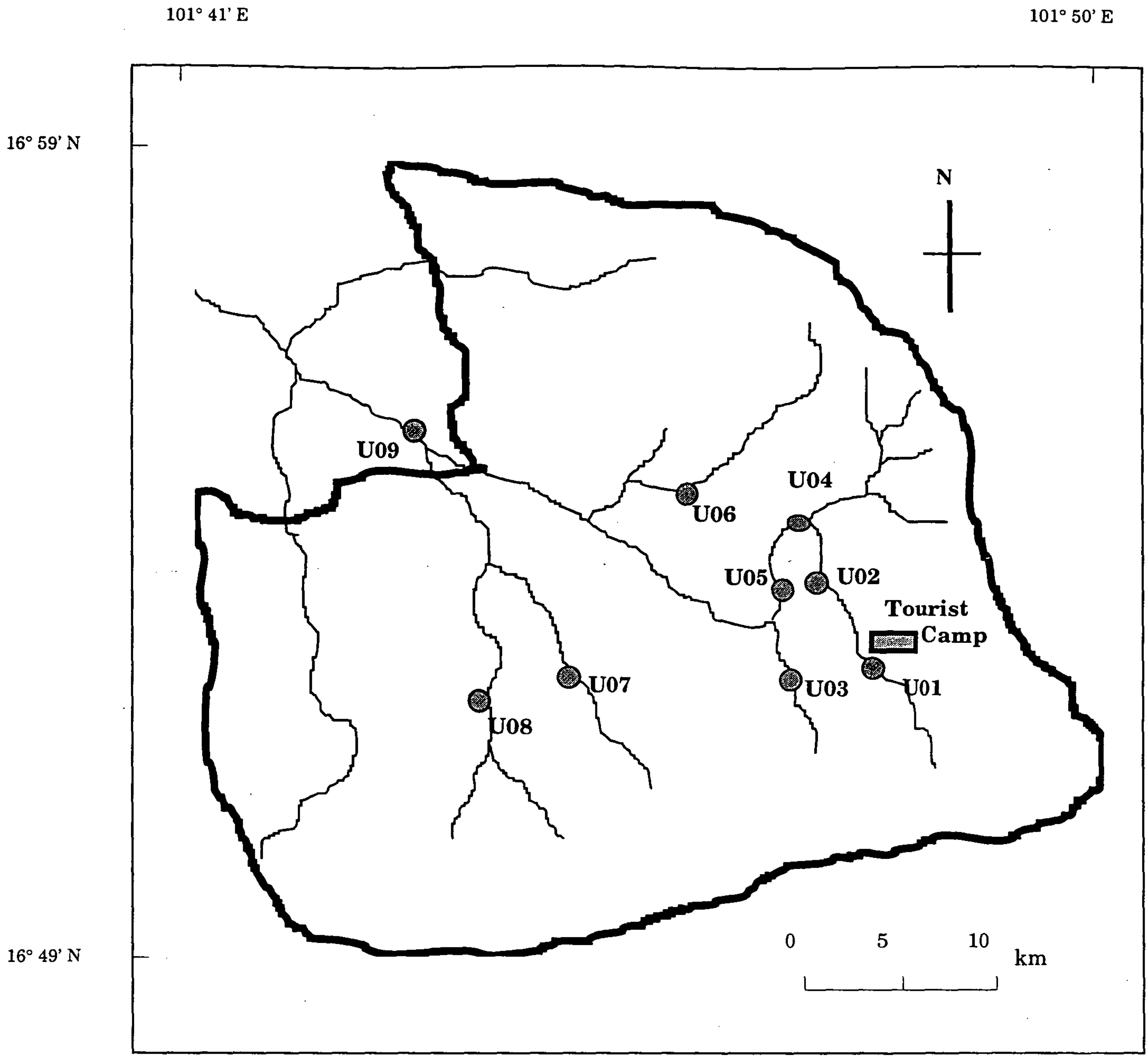


Figure 6.1 Sampling sites in the Phukradueng National Park

Site U01 differs from the other sites in that it receives underground water from the substratum. It has become a large reservoir which supplies water for use by the Park office and visitor camps. The substratum of this site is mainly silty loam whereas the other sites are rocky. The surrounding vegetation is mostly grassland with scattered patches of pine trees, and is located about 2 km south-west of the tourist camp.

The site U02 substratum is bedrock which is colonised predominantly by the shrub *Melastoma normale*. Its riparian strips are mainly temperate species, especially hornbeam *Carpinus viminea* and chestnuts *Castanopsis* spp. This site is semi-open with a canopy cover of 70 percent. Its bank is lined with mosses and several species of aquatic weeds. Leaf litter is deposited sparsely in this sampling stretch. This stream has shallow waters with moderate current speed.

Site U03 is located in dense, tall evergreen rainforest of which the dominant trees are *Dacrydium elatum, Acer calcaratum, Castanopsis acuminatissima* and *Podocarpus neriifolius*. The sampling locations are largely shadowed by big trees so that the light penetration is only 10 percent and the temperature under the canopy is relatively cool all year, even during summer. Mosses and lichens grow profusely on the tree trunks and the moist stream banks are heavily colonised with mosses and ferns. This site is in a pristine ecosystem and features abundant flora and plentiful birds, mammals and terrestrial insects. Its bedrock substratum is evenly overlaid by fine sand, gravel, pebble, cobble and boulder and exposed substrate surfaces are usually covered by bryophytes and epiphytes. The waters in this site are relatively shallow with moderate flow rates.

Site U04 substratum is almost entirely bedrock, perforated with numerous small holes, but there are few boulders situated on top of the bedrock. The forest community of this site is similar to site U03 but with less shading canopy of approximately 70 percent. Unlike site U03, this sampling site is located in a pine-oak-savanna community. Moss and weed communities also grow abundantly along its stream banks.

The substrate of site U05 is almost entirely bedrock. It is located in evergreen forest. The waters are very clear, shallow and with moderate flow. Mosses and ferns densely line its stream banks. This site is at a similar altitude to site U03, but has less dense forest cover.

The site U06 located at an elevation of 960 m.s.l, which is rather lower than the former stations. The substratum consists of mostly bedrock, which has a mosaic of many small holes. The water level is shallow and flows across the bedrock at moderate speed. A particular feature of this site was many fixed cases of caddis flies of Goeridae, Hydropsychidae and portable cases of Lepidostomatidae. All were widespread over the bedrock and conspicuous to the naked eye.

Site U06 is dominated by the beautiful red flowering *Rhododendron simsii* which grows abundantly along the riparian zone. This sampling site is relatively more exposed to sunlight with only approximately 30 percent shading over the stream stretch. The stream receives waters from the upper plain grasslands where several tall grasses grow abundantly, especially *Imperata, Saccharum* and *Themeda.* Such grasslands are a significant refuge of wild elephants which reside in this particular place.

Site U07 is located in the southwestern sector of the summit plateau, and is surrounded by pine-oak savanna vegetation. It is surrounded by the pine-oak savanna vegetation. This site is relatively moist with its stream banks covered mostly by dense moss patches. The site is quite open with only about 50 percent forest cover. Several small oak trees are growing sparsely along the riparian zone, mainly *Quercus acutissima* and *Q. aliena*. Further beyond the stream banks, plant communities are dominated by shrub species including *Lyoniao valifolia, Vaccinium sprengelii* and *Mekastoma normale*.

The substratum of site U07 is bedrock covered by epiphytes, many fixed mineral retreats of caddisfly Psychomiidae, and are readily observed spread over the streambed.

Site U08 is located at the western end of the top plateau. Its stream generally runs across the pine-oak-savanna community, although the actual sampling site is located between grasslands. Its substratum is bedrock colonised by filamentous algae. The thick riparian vegetation at this site provides around 70 percent canopy shading to the stream. Mosses and weeds grow profusely on the stream banks. The water level is more shallow, but relatively fast flowing.

The last site U09, is located downstream in evergreen forest. Its substratum is bedrock with abundant overlying large boulders. In this site, many mayflies could be seen in edge waters with less current speed. On boulder surfaces, there are abundant bryophytes and numerous silky cases of caddisfly *Micrasema* sp. were found. This sampling site is fully exposed to sunlight. Shading available for aquatic fauna is mainly from the shadow of large rocks.

Dominant plants at site U09 are several evergreen trees, such as *Acer calcaratum*, *A. laurinum* and *Schima wallichii*. The weather was relatively cool and wet on all visits. This site, is in fact where the waters from all streams in this plateau catchment are joined and thus become the Pong river (see Fig.6.1).

Materials and methods

Sampling regime

Sampling of benthic macroinvertebrates was conducted on three occasions: in October 1995, February and May 1996. Each sampling cycle over the nine sites took one week to complete.

Sampling equipment

Aquatic macroinvertebrates were sampled using a Wildco® Surber Stream Bottom Sampler (0.30 x 0.30 m with 500 µm mesh aperture). At each site, six replicate samples were randomly located over a stream stretch approximately 50 m in length. The samples collected were then preserved in 70 percent ethyl alcohol in plastic bags and sorted at the base camp. The sorted specimens were then stored in vials of 70 percent ethyl alcohol. The specimens were returned to the laboratory at Khon Kaen University, Department of Biology and identification of all specimens made with the use of the keys as described in Chapter 2.

Due to the remote nature of the sampling sites, which are difficult to access, the water physicochemical analysis, including flow rate, dissolved oxygen (DO), total dissolved solids (TDS), water temperature and conductivity could be made only in the field. The current speed was measured by a Genuine Gurley Current Meter Model D625, at mid-depth of each sampling replicate, DO and temperature by a Dissolved Oxygen Meter YSI Model 57, TDS and conductivity by a Traceable™ Conductivity Meter Model 4062. The site elevation measurement used a Global Positioning System-GPS, Model Ensign XL.

Study design

To address the five questions raised earlier, the study proceeded as follows:

1. All benthic larvae quantitatively collected from all stations were analysed for changes in their community structure through space (nine stations) and time (three different occasions: immediately post wet season October, cool dry February and wet season May).

2. The pristine site U03 was chosen to more closely investigate small-scale heterogeneity within a stream reach. Six quantitative Surber samples were collected from each of boulder, cobble, pebble, gravel and sand microhabitats.

3. Nutrient-rich biotopes, namely leaf pack, moss, edge-water weed root and bare bedrock (control) substrates were selected to compare benthic community distribution within them. Six samples were taken in each biotope. Again, site U03 was the investigation site.

4 To document any differences in the benthic community in riffle and pool areas, site U03 was chosen as the examination site. Six replicates were sampled from each of the riffle and pool areas.

5 Benthic larvae were sampled from riffle and pool areas at sites U02 and U03 to compare intra- and inter-site variations (six replicate per riffle or pool, total 24 samples). This also compares the effect of the different vegetation types of each and whether this factor is more influential than the internal riffle and pool factor.

All analysis associated with procedures 2 to 4 used data collected in February 1996 at site UO3. This served to exclude the effect of seasonal variation (spate) on the benthic community.

Data analyses

Univariate statistics were used for summarising water quality, benthic community structure, individuals and species variations. Multivariate cluster analysis UPGMA was used to compare benthic community density assemblage in various biotopes, and riffle and pool areas. The Kruskal-Wallis test was used to determine species which are significant discriminators between substrate scale, riffle and pool samples. The multivariate analyses employed PATN software (Belbin 1995).

Results

The results are presented in 5 sections. The first section describes water physicochemistry variation while the latter four sections describe aspects of the macroinvertebrate fauna.

Section 1: water physicochemistry

Water quality in the Phukradueng streams is relatively good. The average DO level is high at 7.5 mg/L, and there was no significant difference in DO levels between the sites ($F_{8,18}$ =1.0699, P=0.0425). However, some stream sites in dense evergreen forest had slightly higher DO levels than the other sites (Fig.6.2a) presumably due to the lower water temperatures there. All streams had DO values greater than 7.0 mg/L on all sampling occasions and mean values do not differ significantly between months ($F_{2,24}$=3.063, P=0.065).

Both electrical conductivity (EC) and TDS levels in the Phukradueng streams were very low, averaging 11.6 micro*S*/cm and 12.8 mg/L respectively. Such low levels in Phukradueng streams are in marked contrast to the Pong river downstream. For example, in October 1995, the means EC and TDS of the Phukradueng waters were 19.5 µ*S*/cm and 14.1 mg/L, while in the Pong catchment were 220.0 µ*S*/cm and 158.8 mg/L, respectively. Corresponding values at site P01, the nearest Pong catchment site to the Phukradueng (~50 km distant), were higher than in any of the Phukradueng streams.

There is a slight EC variation between months. In February the mean EC in Phukradueng streams was 19.5 microS/cm, while in May and October the EC values were 6.7 and 8.8 microS/cm, respectively ($F_{2,24}$=6.562, P=0.005).

The pH in Phukradueng streams averaged 7.2 and showed no significant variation between sites. ($F_{8,18}$=0.963, P=0.493). The mean water velocity in Phukradueng streams was 0.59 m/sec which may be classed as relatively moderate flowing, and was approximately the same at all sites ($F_{8,18}$=1.156, P=0.376). All sampled streams in the Phukradueng have approximately the same depth ($F_{8,18}$=1.011, P=0.462) which averaged 0.15 m.

The physicochemical feature most subject to changes is velocity which varies between sampling months ($F_{2,24}$=4.9500, P=0.0154). The mean water velocity was more than twice as high in the monsoon month of May (0.93 m/sec), than in cool dry month of February (0.39 m/sec) (Fig.6.2b).

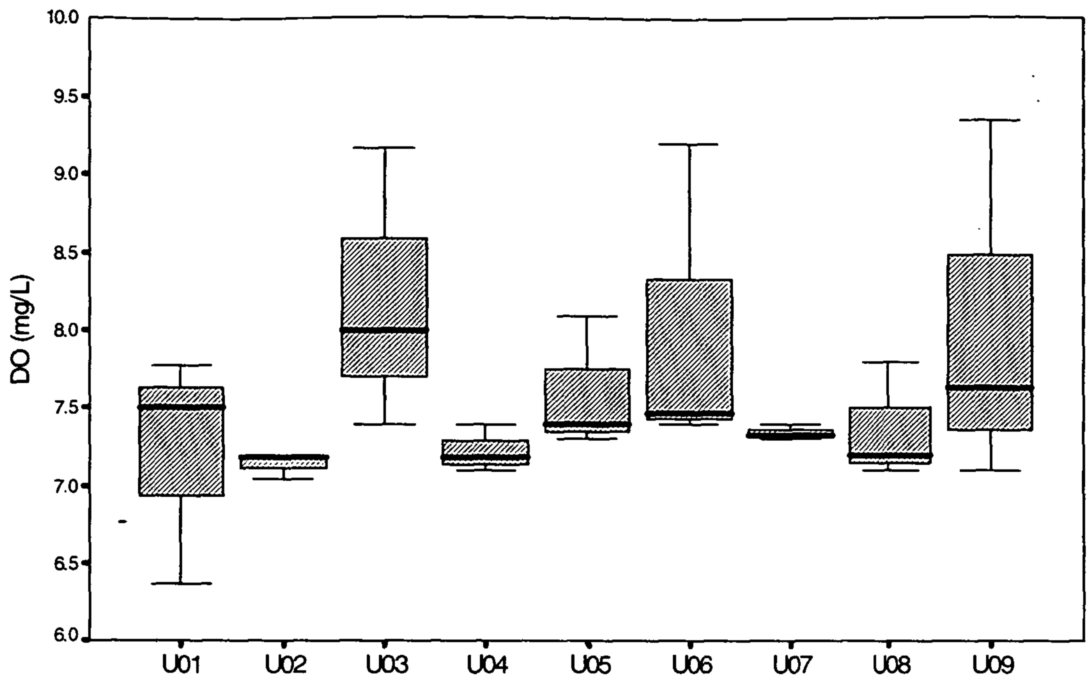
Another seasonal variable factor was water temperature, which was lower in February (mean of 17.9 °C), and higher in October and May (20.4 and 21.9 °C, respectively) ($F_{2,24}$=16.4401, P=0.001).

In summary, the water quality in Phukradueng streams is good and all sampled waters across the catchment show minimal pollution. This contrasts with the Pong and Cheon in which water quality changes considerably between sites within the same landscape unit.

As the major water quality variables showed no marked differences between sites, then correlations between benthic taxa assemblages and water quality among sites were not sought in this study.

The streams in the Phukradueng National Park exhibit baseline unpolluted water conditions. This is rarely found in other catchments in this region (although its BOD-organic determinant cannot be measured here). Therefore, this catchment has great value as a reference to compare to other more impacted catchments in northeast Thailand.

(a)



(b)

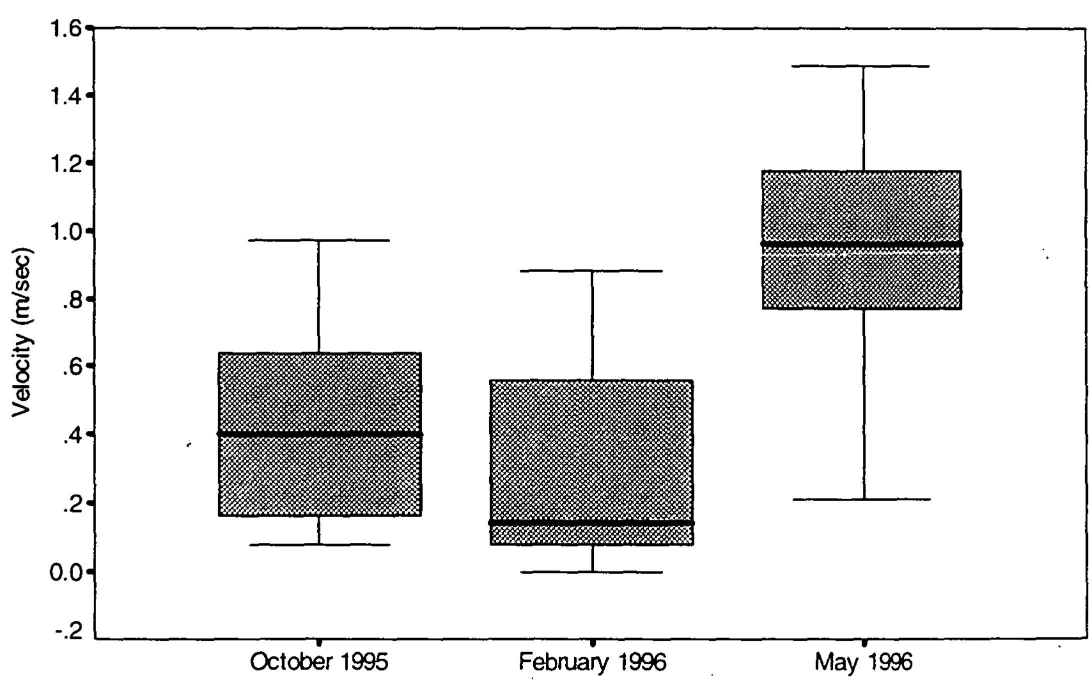


Figure 6.2 Boxplots of (a) dissolved oxygen between sampling sites, and (b) water velocity between sampling months

Section 2. General features

(1) Taxa abundance

One hundred and eighty species of macroinvertebrates were recovered from a total of 25608 individuals. The most diverse group was trichopteran larvae with 47 species. The second and third ranked groups were coleopterans and odonatans with 38 and 28 species respectively. Appendices 6.1 and 6.2 give details of all species and individuals found.

Figure 6.2 shows the ordinal composition found in the Phukradueng National Park from all sampling sites and occasions combined.

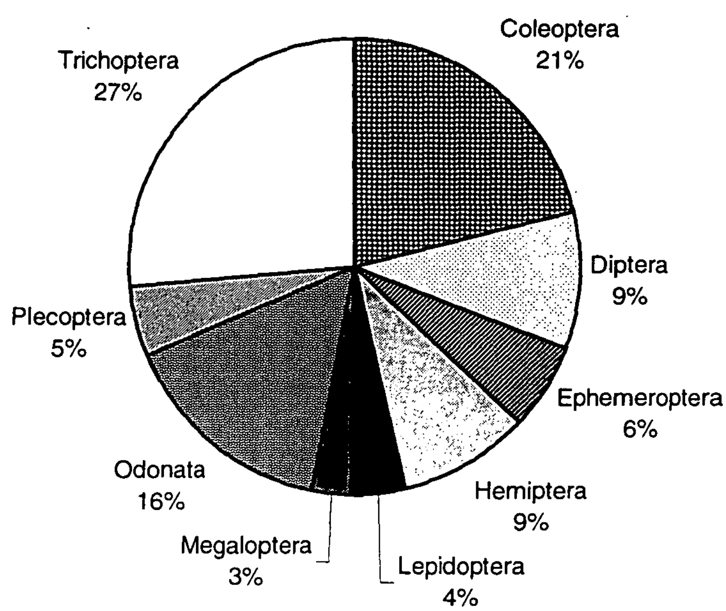


Figure 6.2 Percent species composition per order of all sampling sites in the Phukradueng National Park, Thailand

(2) Spatial taxa variation

Spatial of distribution macroinvertebrates varied between sampling sites. Three sites, U03, U04 and U02, are distinctive for their highly diverse benthic larval assemblages, while site U01 has minimal species richness (Fig.6.3).

The richest species assemblage of 93 species occurred at site U03. The next most diverse were sites U04 and U02 in which 80 and 73 species were discovered respectively. At all three sites, caddis flies and water beetles constituted the largest taxon groups (Fig.6.3).

Certain environmental factors seem to correlate to the benthic species richness at various stream sites, especially different vegetation communities and substratum types.

Site U03 had a diverse substrate of mixed rocks, cobbles, pebbles and sand approximately in equal proportions. The site is located in undisturbed evergreen forest, with its vegetation community very dense, and canopy shading is approximately 80 percent. The stream banks are covered in a mosaic of mosses and ferns. This site may be among the most pristine original rainforests left in Thailand.

The water in this site is transparent with high oxygen content averaging 8.4 mg/L with 91% saturation. The water level range is 0.15-0.20 m with a slow current 0.08 m/sec. The dissolved inorganic ions in this site measured by EC is also very low with an average of 8.6 μS/cm (compared to lowland waters of the Pong averaging 237.2 μS/cm). It is apparent that the waters in site U03 are very clean and diverse community.

Site U04 also has outstanding benthic species richness with a total of 80 species. This sampling site was also located in evergreen rainforest at approximately the same elevation as site P03 (see also Table 6.1). However, this site is rather different from site U03 since it has minimal vegetation cover locally. The stream bed in this site is mainly bedrock with rocks and cobbles. The water quality, measured as DO and EC, does not differ from site U03.

Caddisfly retreats of Psychomiidae and Goeridae cases are conspicuous features of site U04. The first appears to be fixed to the streambed while the second appears as clumped fragments of tiny grains adhering to the perforations in the stream bedrock.

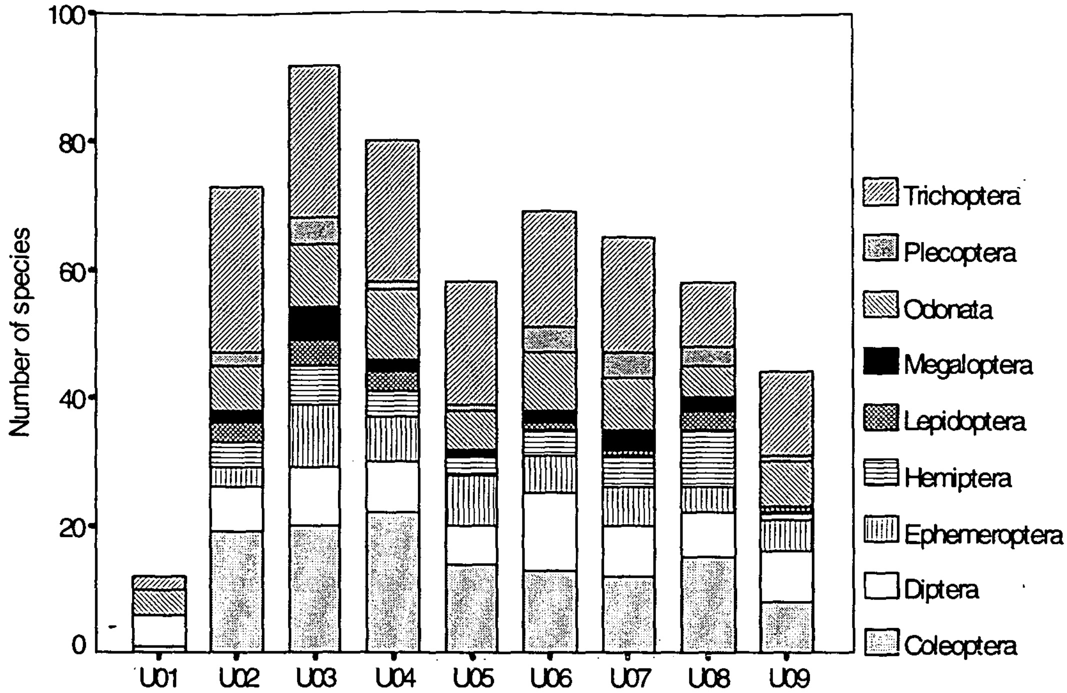


Figure 6.3 Number of macroinvertebrate species assemblages per sampling site in the Phukradueng National Park

The whirligig beetle, *Dineutus* spp., was present at U03 on all three sampling occasions has been observed in cool and clear stream waters in undisturbed forests elsewhere. I always find this taxon in protected and cool forest streams, for example, in Nam Nao National Park, and most sites in Phukradueng National Park. It has never been found in any disturbed waters, and therefore the existence of *Dineutus* spp. may be indicative of pristine ecosystem streams.

Site U02 in the pine-oak-savanna community, also has a highly diverse benthic community, totaling 73 species. This site is located in a rather open space between pine-oak-savanna vegetation but it has thick riparian vegetation, and the stream banks are covered densely with mosses and ferns. Its stream substratum is mostly bedrock partly covered with periphyton.

Caddisfly species dominate the benthic species composition in sites U02, U03 and U04 despite their different vegetation communities. Mayfly species, in contrast, are less abundant in Phukradueng National Park (see Appendix 6.1). Indeed, the lower catchment-the Cheon (800 m.s.l) as has more diverse mayfly species than the Phukradueng (1200 m.s.l) (see Chapter 2).

Site U01 is at the highest altitude and has the simplest benthic species assemblage with 12 species (Fig.6.3). This site in fact is the origin of the Pong river where the seepage waters arise from underdrain subsurface soil, then flow downstream to where site U02 is located (Fig.6.1). This site is located in open grassland with fragmented pine tree community but with no distinct vegetation stripe. Its substrate is silty clay. The waters in this site are rather reservoir-like.

The dominant taxa in this site is Diptera which implies that the substratum type is another constraining factor which srongly determines the nature of the benthic larval community. Sites U01 and U02 were located approximately the same elevation and in similar vegetation types, but have different substrate types resulting n very different benthic communities.

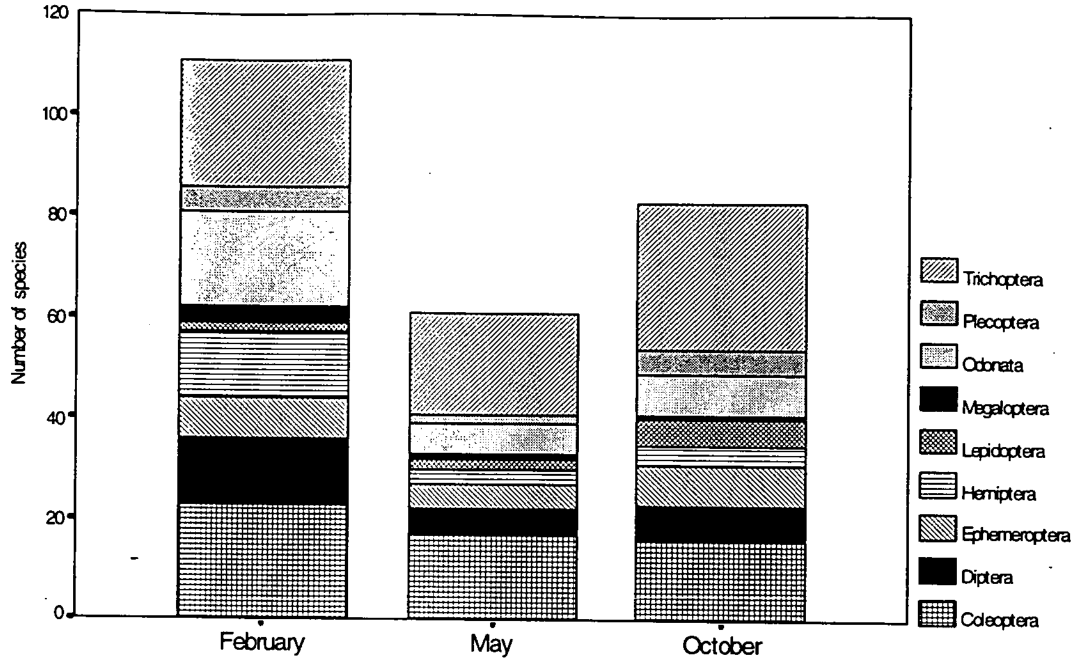
Overall this National Park with high altitude healthy ecosystems has very diverse benthic larval communities. Numerous species found in this Park were not discovered in lowland waters of the Cheon and the Pong. Those parts of these catchments located near the Phukradueng are at lower altitude (200-800 m.s.l) and more open vegetation communities. Factors associated with altitude and catchment forest type seem to be very influential in determining community species richness. At different scales between streams in the same plain associated with different substrate types and vegetation communities, correspondingly different benthic community structure can be observed.

(3) Temporal abundance

Unfortunately this study was not allowed to sample at more frequent intervals in this Park (prohibited by Thai National Forestry Conservation Law), however the trends of benthic species variation through time are obvious.

In dry and cool February, sampling recovered 111 species, while in May and October 62 and 83 species respectively were discovered. This trend can signify the fluctuation regime through time; in early raining period May, the taxa abundance is reduced and later increases in post flooding October month. Finally, benthic larval species reaches its peak richness in late cool month (pre-flooding period) February.

(a)



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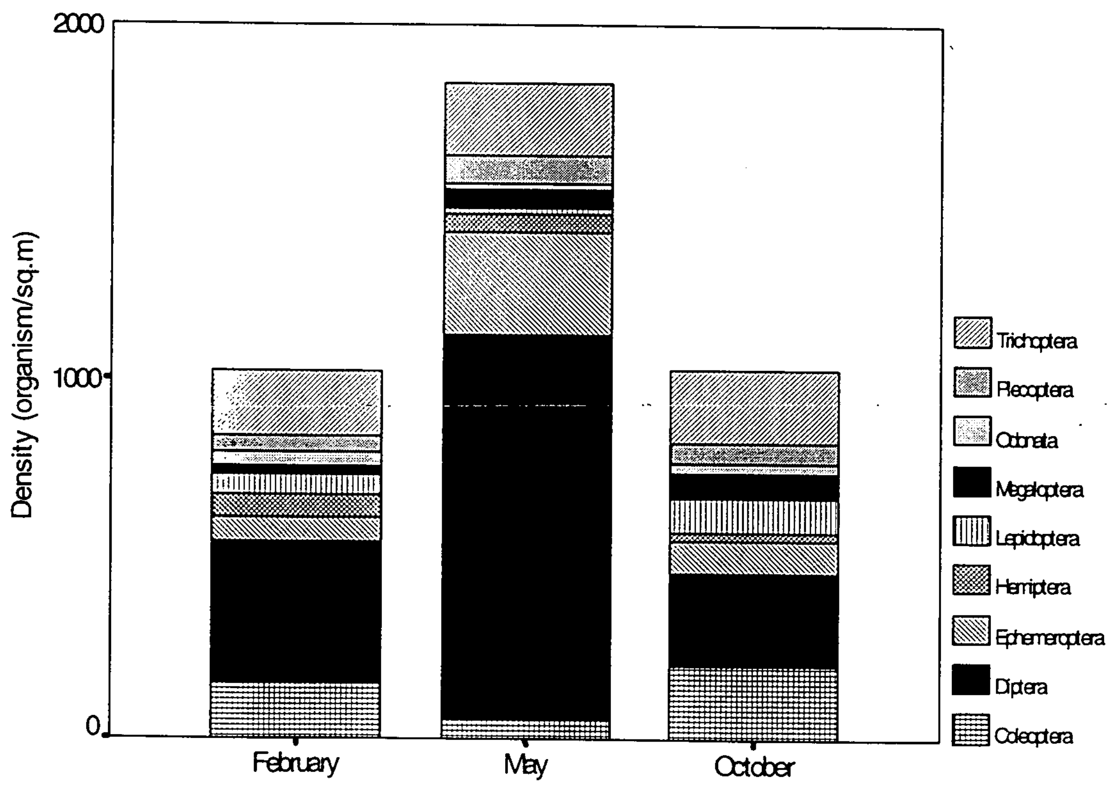


Figure 6.4 Temporal variation of benthic taxa (a) species richness, and (b) taxa density in the Phukradueng National Park

Almost all the benthic orders increase or decrease seasonally in species richness in accordance with the general overall trend (Fig.6.4a). However, the density of organisms in each order appeared to fluctuate in different ways (Fig.6.4b).

Three taxa, Diptera, Ephemeroptera and Plecoptera increased their density in the early raining month of May. The highest density was of *Simulium* sp. which increased from 302.2 organism/m^2 in February to a maximum density of 3868.4 organism/m^2 in May.

During May, most *Simulium* sp., were in the pupal stage and appeared as a dense black carpet over the streambed in most shallow fast-flowing riffle areas. Among *Simulium* colonies were also found many pupae of the caddisfly *Ceumatopsyche malaysiensis,* the only caddis species were increased its abundance in this month with an average density of 2096 organism/m^2. Its case was mostly found fixed to the bedrock in relatively shallow strong current water.

Stream depth was a factor which also determined the presence of *Simulium* and *C. malayseinsis*. Both were absent in May from the stream sites deeper than 0.20 m. In prior sampling months, neither species was found abundantly in this catchment. The results therefore suggest that these two species are definitely site-specific and also time-specific for pupation. Both characterise very shallow fast-flowing streams in the early wet season.

The mayflies Baetidae *Baetis* sp1 and Heptageniidae *Nixe* sp also increased their density in May. These two species are found widely in stream stretches with slow current, in contrast to the habitat of *Simulium* sp. and *C. malaysiensis*. Both mayflies mostly dwell in shaded stream areas while *Simulium* sp. and *C.malaysiensis* colonise in rather exposed areas. Another contrasting feature between these four abundant taxa is their developmental stage in May. *Simulium* sp. and *C. malayseinsis* are mostly in the pupal stage whereas the two mayfly species were mostly still in early instars.

Mixed nymphal stages were typically found among almost all species recovered, a finding which supports the notion that in tropical climates there is multivoltine development, a phenomenon markedly different from temperate zone faunas.

(4) Concluding remarks

The major findings about the benthic macroinvertebrate fauna richness and distribution in the pristine Phukradueng National Park are as follows:

1 The most diverse benthic larval fauna was found to exist in pristine streams with mixed substrate types located in tall rainforest.

2 Substrate is the major factor which determined the diversity of benthic species at sites of similar altitude.

3 Greatest benthic species diversity in the Phukradueng National Park occurred in February (of the months sampled). This is consistent the finding reported in Chapter 3 this is the time of year when benthic larval species in the tropics reach their peak diversity and abundance.

4 There is a general trend of species richness decline reflecting the seasonal discharge regime. Benthic species decrease from their highest diversity in February to their lowest in May and later gradually increased in October. This is presumably due to life-cycle phenology rather than any external impacts (there are no substantial pollution inputs in this Park).

5 The study results revealed phenological differences associated with the nymphal development stage, and also evidence of habitat partitioning between co-existing species, for example, in the case of *Simulium* sp. and *C. malaysiensis*.

6 Within each microhabitat, certain factors condition the occurrence and distribution of benthic species at a site. Such factors are presumably (i) substrate specific, bedrock, cobble, pebble, gravel or mixed substrate types, (ii) available nutrient sources, leaf litter and algae (periphyton and neston) and edge-water plant roots, and (iii) riffle and pool phenomena. All these presumptive factors raised here are explored further in the next sections.

Section 3 species variability among different microhabitat templates

(1) Variation of taxa between different substrates

There is a marked difference in species richness and abundance between each of the four substrate types (Fig.6.5). Both measures are highest in boulder substrates and lowest in sandy substrates suggesting that in general, the benthic species assemblage declines as the substrate particle size decreases (Fig.6.5).

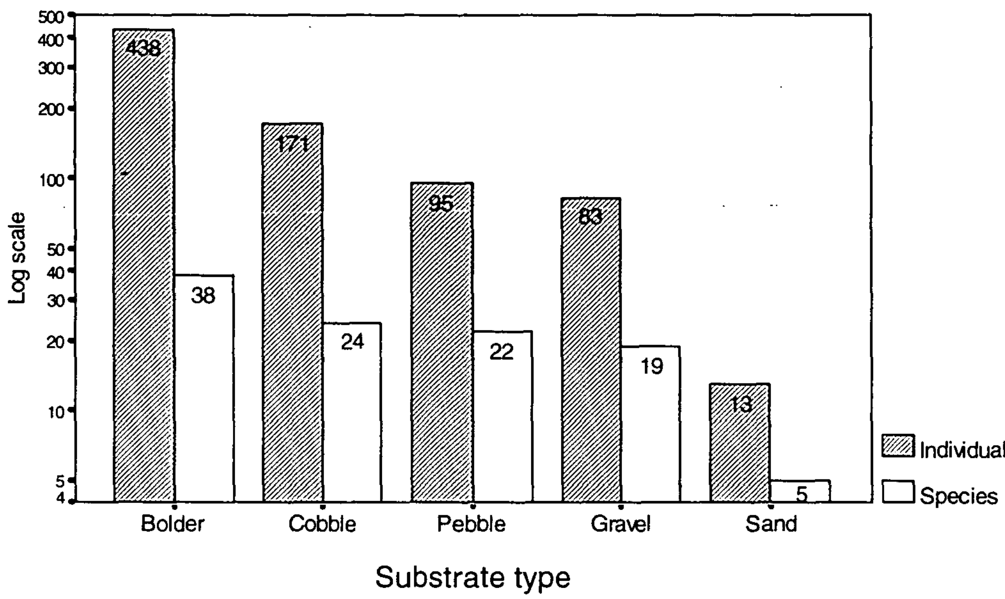


Figure 6.5 Numbers of benthic larval species and individuals found on each substrate type

Water beetles clearly prefer to associate with boulders where periphyton is plentiful (Fig.6.6), and various species of Dytiscidae, Hydrophilidae, Hydrochidae and Elmidae were more abundant in the boulder biotope than in other substrate types. Water beetle species richness decreases from 13 species in boulders to 6, 8 and 5 species in cobble, pebble and gravel substrates, respectively. No water beetle larvae were found in sandy substrates. *Stenelmis* sp., *Laccobius* sp. and *Hydrochus* sp. were much less abundant in substrates other than boulders.

Caddis fly abundance was also reduced on finer grained substrates (Fig.6.6). The brachycentrid caddis *Micrasema* sp. was an indicative species with 13 individuals in boulders but only 3 specimens were extracted from each of the cobble and pebble samples. None were found in gravel or sandy samples. Similarly, four other caddisfly species, *Ecnomus* sp., *Polycentropus* sp., *Lepidostoma* sp. and *Tinodes* sp., were rarely found in gravel and sandy substrates.

Diptera also decreased in abundance according to substrate size. For example, Chironomidae midge larvae showed a clear reduction from 150, 40, 32, 21 and 1 organisms in boulder, cobble, pebble, gravel and sand, respectively. The ceratopogonid *Bezzia* sp. also showed the same trend.

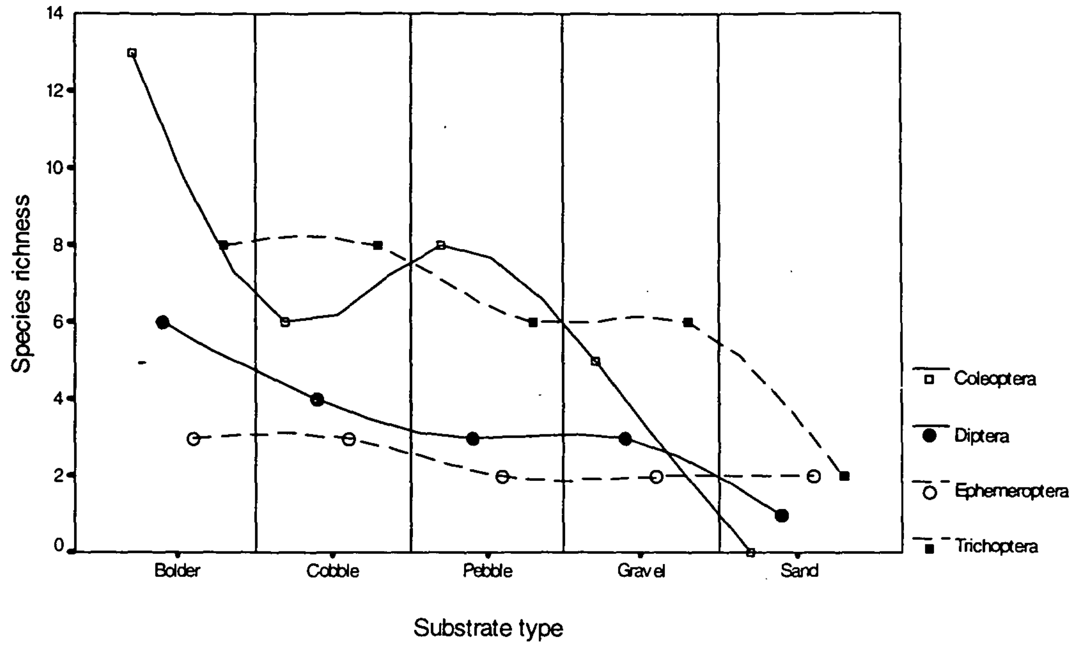


Figure 6.6 Species richness per major taxa groups on each substrate type

In contrast, Ephemeroptera at the ordinal level did not clearly associate with any particular substrate type. The study found 36 mayfly specimens from all samples: 16 *Nixe* sp., 13 *Letophlebia* sp., 1 *Habrophlebia* sp. and 6 *Baetis* sp1. Most *Letophlebia* (8 specimens) were found mixed with other species in boulder samples. Most *Nixe* sp. (6 specimens) and *Baetis* sp1 (4 specimens) were recovered from pebble samples. In the sandy samples, a single *Nixe* sp. and *Leptophlebia* sp. were present. When compared to other taxa groups, mayflies are rather widely distributed. However, they can be specific to a particular habitat at the level of species.

Hemiptera and Odonata were mostly restricted to boulder substrates. Of 51 water bug specimens found, 49 were recovered from boulder samples and only one each from cobble and pebble substrates. Similarly, of 16 odonatan specimens 14 were from boulder samples while one specimen each came from cobble and pebble samples. Appendix 6.3 summarises all benthic taxa found in all substrate types.

(2) Sample clustering

The clustering of samples by UPGMA using total taxa abundance data, is shown in Fig.6.7. In general, the samples are clustered according to substrate types, and mostly arranged in order from the largest substrate size (boulder) to the smallest (sand). The diversity of benthic species also decreased from the upper cluster (b1-b3) to the lowest (s1-s2).

Figure 6.7 Dendrogram of sample clusters based on substrate particle size (b=boulder, c=cobble, p=pebble, g=gravel, s=sand)

Substrate sample group p2 (pebble sample 2) is an outlier, being clustered with the gravel samples (g's). Possibly the coarse scale used in this study for discriminating substrate sizes between gravel and pebble classes may not be adequate. However, the overall trend of benthic species abundance reflects the substrate type.

(3) Summary of major findings

Major findings of the relationship between taxa and substrate types are as follows:

1 Different microhabitat types are associated with different magnitudes of benthic species richness.

2 There is a vast difference between taxa abundance within a site when sampled from different substrate types. The boulder substrate supports colonisation of more diverse benthic larval species than cobble, pebble, gravel and sand.

3 The finding of higher species richness in boulder substrates poses the question of whether this due to habitat specialisation, nutrient availability, or enemy-free space. Clearly, all of these can be influential, for example, (i) certain taxa have specific habitat needs, e.g. psychomiid caddisflies build their fixed retreats on large firm rocks, and (ii) local nutrient enrichment may be influential since boulders support dense periphyton and mosses available for grazing.

4. This section also highlights the importance of careful habitat selection for sampling. This poses many questions about the validity of results caused by habitat rich-poor phenomena when conducting environmental impact assessments (EIA) using benthic macroinvertebrate fauna, particularly at sites with multiple habitat scales prevailing.

Some attempts were made to further address some of the above points. The following section deals with various potential food sources in the aquatic environment which may contribute some "clues" about the relationships between benthic species and their small scale local distribution.

Section 4 relationship between benthic species and food sources

(1) General taxa assemblage pattern

Benthic taxa assemblage patterns in four major available microhabitats were found to be considerably different. Bare bedrock (reference site) has lowest benthic taxa richness while the most diverse benthic assemblage is in edge-water weed roots (the root and siphon parts which extend into the water body) (Fig.6.8). Appendix 6.4 summarises the individual invertebrate density in four nutrient substrates.

Only 14 species occupied the bare bedrock habitat. The mayfly *Baetis* sp1 (Baetidae) was the most common species found to live on the bare bedrock substratum. Only one water beetle *Stenelmis* sp. (Elmidae), four species of Odonata, *Cordulia* sp., *Davidus* sp., *Sieboldius* sp. and *Acisoma* sp. and several caddisfly species, particularly *Micrasema* sp., *Hydroptila* sp., *Lepidostoma* sp., *Molanna* sp. and *Tinodes* sp., were found on this substrate.

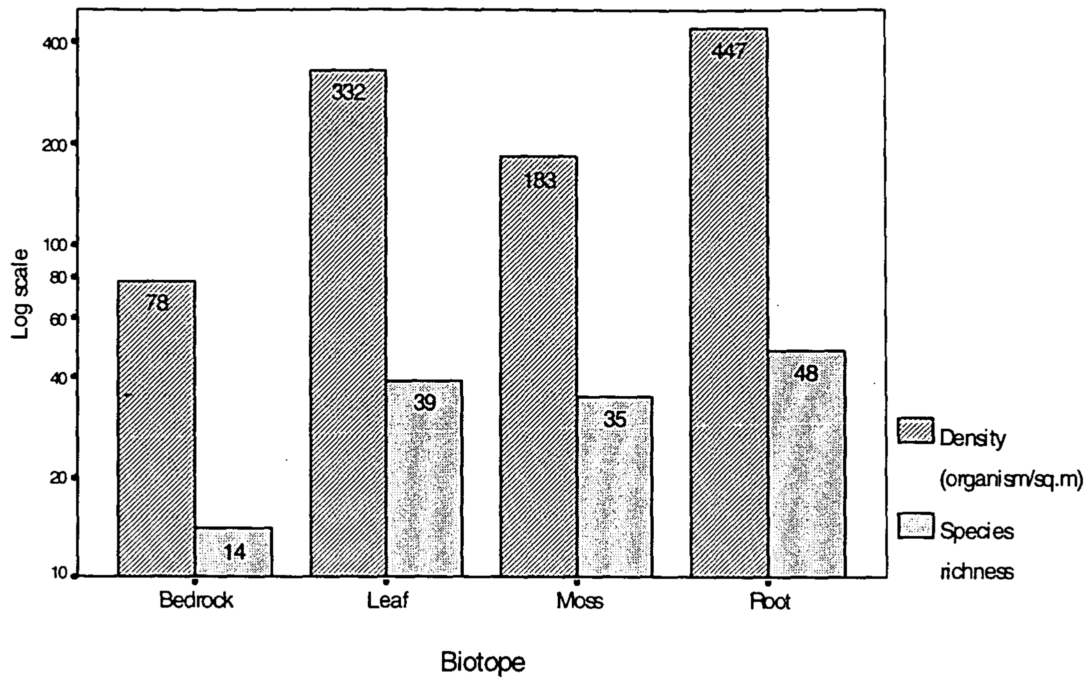


Figure 6.8 Benthic species richness and larval density in each biotope *(numbers represent cumulative species richness and average density respectively)*

Among the conspicuous benthic species dwelling on bedrock, two caddisfly species are clearly visible to the naked eye. These are *Lepidostoma* sp. and *Molanna* sp. The first species is striking with its colourful tiny square-block case while the second is like a tiny pocket made of sand grain moving about on bedrocks. However, these two species are also abundant in leaf pack, moss and edge-water vascular roots as well. These two species were often seen on bedrock in quiet, cool, relatively slow current waters in most of Phukradueng National Park's streams. They were both rare in the lower catchment of the Pong and the Cheon.

Most benthic species are living together attached to substances related to their preferred nutrient sources which are often derived from leaf packs and hydrophyte roots (Fig.6.8). Moss is another distinct microhabitat which several benthic species favour. In this study, the bryophyte samples taken were mosses abundantly growing as a surface layer on rock and bedrock on the streambed.

It appears that the vascular roots in the littoral zone are the most significant refuge which supports diverse benthic larval species.

Observation suggests that all benthic larval species shared this microhabitat as a community of mixed species attached to the roots. As well, the larvae were typically of mixed development stages. Multistage nymphs was also common in the moss substrate, whereas on bedrock and leaf packs, most of the benthic larvae recovered were in the later nymphal stages.

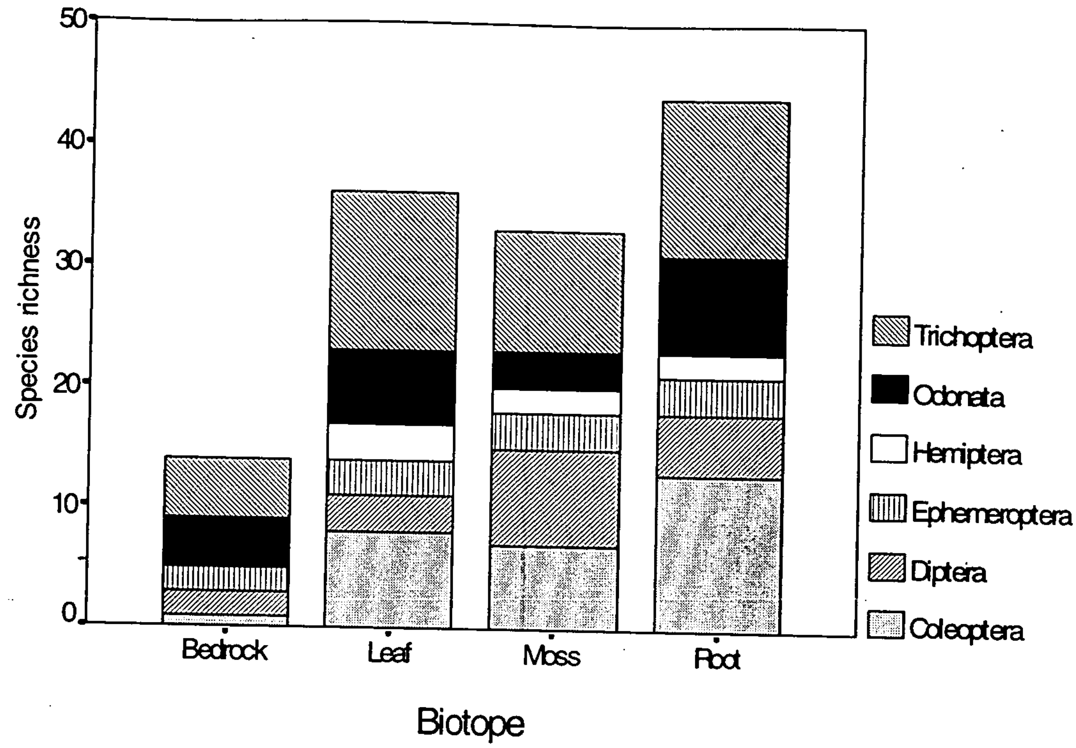
(2) Species-microhabitat interaction

The study further found that there was considerable evidence of association between various species and aspects of the microhabitats.

(a) Coleoptera

Thirteen of the 15 water beetle species inhabited vascular hydrophytes (Fig.6.9a), while 8 and 7 species were located in leaf packs and moss respectively. Only one species, *Stenelmis* sp., was found living on bare bedrock. All Dytiscidae species were abundant among the hydrophyte roots, including *Copelatus* sp., *Hydaticus* sp., *Laccophilus* sp. and *Neptosternus* sp. *Hydaticus* sp. was also found in leaf pack and moss microhabitats. In leaf packs samples, *Laccophilus* sp. and *Neptosternus* sp were also found but less commonly than among vascular roots.

(a)



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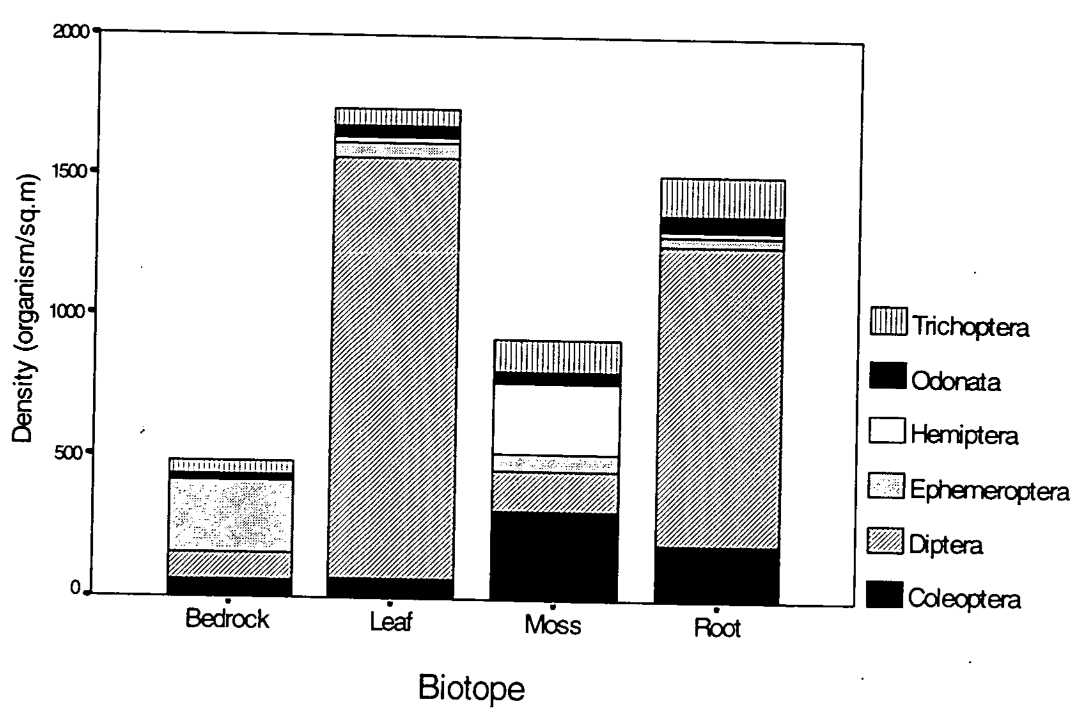


Figure 6.9 Benthic taxa composition between biotopes (a) species richness, and (b) relative density

All three elmids, *Ordobrevia* sp., *Stenelmis* sp. and *Zaitzevia* sp., were found in moss samples. *Stenelmis,* in particular, occupied all four microhabitats but was relatively more abundant in the moss substrate. *Zaizevia* sp. was found only in moss samples while *Ordobrevia* sp. was discovered in both moss and leaf pack samples.

Several species of Gyrinidae, Hydrochidae, Hydrophilidae and Psephenidae were found on vascular roots. Some Hydrochidae and Hydrophilidae species live in moss and leaf pack samples. *Laccobius* sp. preferred to reside in moss (1624 individuals) rather than in leaf pack (64) and hydrophytes (176).

(b) Diptera

Diptera were much more abundant in vascular hydrophyte roots (2923 individuals) and leaf packs (1660) (Fig.6.9b) than in moss (134) and bedrock samples (12). However species richness was greatest in moss samples (8 species) while hydrophyte, leaf pack and bed rock samples had 5, 3 and 2 species respectively.

Some dipteran species were restricted to the moss substrate: *Pericoma* sp., *Simulium* sp. and *Tabanus* sp. The *Simulium* sp., in particular, was present in the early nymphal stage at this time (February), but it was observed that this species later enters the pupal stage and appears as a black carpet on shallow riffle bedrock areas in May.

(c) Ephemeroptera

Two mayfly species, *Baetis* spl and *Leptophlebia* sp. prefer to dwell only on particular substrates. The first species was plentiful on bedrock and to a minor extent, in leaf pack and moss samples. Only 6 *Baetis* specimens were found from root samples. In contrast, *Leptophlebia* sp., yielded 25 individuals in leaf pack and vascular hydrophyte habitats; only 2 specimens were discovered in moss samples. The heptageniid *Nixe* sp. was the most abundant mayfly in this catchment and can be found elsewhere on shallow water bedrock with shading. This species was also found in moss samples as early instar nymphs, while on bedrock they were middle to late instar nymphs.

(d) Hemiptera

The five species of Hemiptera found were *Agraptocorixa* sp., *Microvelia* sp., *Plea* sp., *Pseudovelia* sp. and *Ranatra* sp. The two most abundant species were *Microvelia* sp. (n=29) and *Pseudovelia* sp. (n=23). *Plea* sp. and *Agraptocorixa* sp. had one specimen each from leaf pack samples. One individual of *Ranatra* sp. was from the root samples.

Of a total of 55 water bug individuals, most *Microvelia* sp. (26 individuals) and all *Pseudovelia* sp. were found in moss samples.

(e) Odonata

Of the sixteen species of Odonata found from all four habitats samples combined, most were associated with leaf (7 species) and root samples (8 species). Abundance of odonatan larvae was highest in root samples (127 from a total of 177 individuals). *Cordulia* sp. and *Lestes* sp. were most abundant in the root samples, with 30 and 81 individuals respectively. *Lestes* sp. was also plentiful in leaf pack samples (20 individuals).

(f) Trichoptera

Caddis flies were rather evenly distributed in relation to microhabitats. Of 18 caddis species, 14 were discovered from each of leaf pack and root samples. Trichoptera was the most diverse order, (n=18 species), while the second was Coleoptera with 15 species.

Some caddis species were highly species–habitat specific, notably case-bearing species, *Helicopsyche* sp. and *Micrasema* sp. Of 122 *Helicopsyche* individuals found, 121 were in root samples while only one specimen was from leaf pack. Most *Micrasema* sp. individuals were found in moss samples (87 specimens) and only a few from root samples (n=1). leaf (n=2) and bedrock (n=7). It was observed that most *Helicopsyche* sp. preferred to attach their coiled case to hydrophyte roots while *Micrasema* sp. preferred to attach its tube case to mosses.

In contrast, the tube-makers *Mollanna* sp., *Mystacides* sp., *Lepidostoma* sp. and the net-spinners *Tinodes* sp. and *Polycentropus* sp., could all be found in approximately equal abundance in both leaf pack and backwater weed roots. However, a two-piece leaf case builder, the calamoceratid *Anisocentropus* sp., was found only from leaf pack samples.

The ecnomid *Ecnomus* sp. can be found almost equally in all sampled types except bedrock. Rare caddis species in this catchment were Rhyacophilidae *Rhyacophila* sp. and Sericostomatidae *Sericostoma* sp., the former species had 4 specimens from root samples and one individual from leaf packs, while the latter had 3 individuals found only from root samples.

(g) Plecoptera, Megaloptera and Lepidoptera

Stonefly, alderfly and moth larvae are also present in these streams but are less abundant compared to other orders.

Thirty two stonefly specimens were recovered, representing two species. *Nemoura* sp. (29 specimens) and *Neoperla* sp. (3 specimens). The most striking feature was that all *Nemoura* sp. were found only in moss samples. *Neoperla* larvae occupied root and leaf pack samples.

All moth larvae were *Potamomusa* sp., and 8 of 12 recovered individuals lived in moss. One individual was recovered from leaf packs and three from root samples.

Seven alderfly individuals were discovered, four from root samples and three from leaf packs. Two species with two individuals each were found, *Neochauliodes* sp. and *Sialis* sp. The first species was recently discovered while surveying benthic fauna for three years across this region of Thailand, while the second can be found elsewhere including lower in the catchments of the Cheon and the Pong.

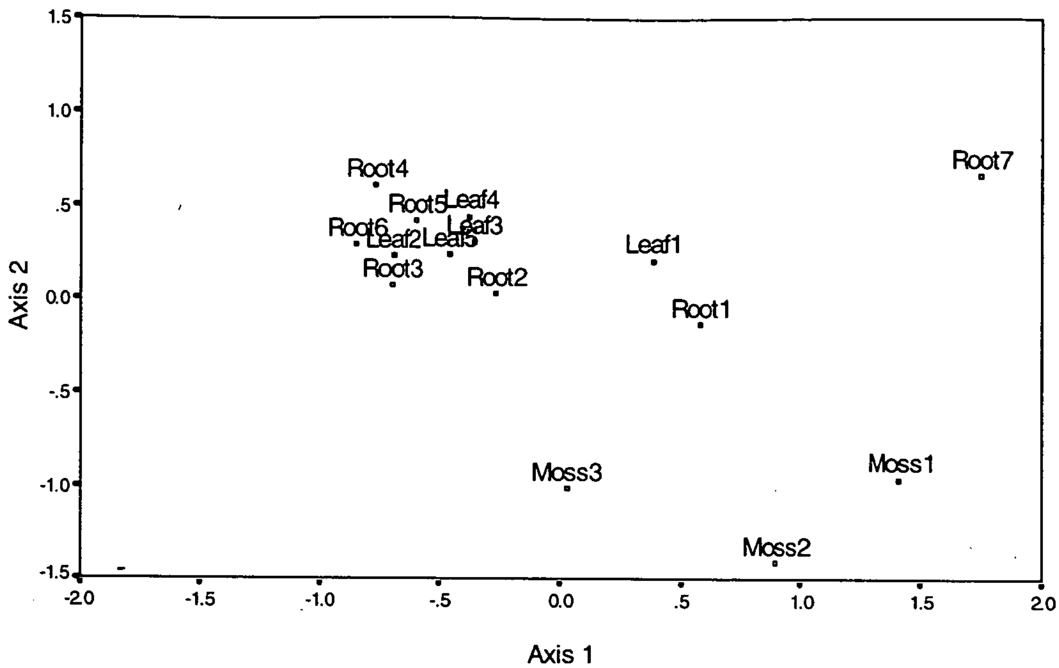
(3) Relationship between dominant macroinvertebrate groups and certain substrate types

HMDS ordination of samples from three substrate types using taxa density data revealed associations with habitat (Figs.6.10a and 6.10b). Samples from roots and leaf packs mostly aggregated together, while the moss samples were located more distantly in the ordination space.

The arrangement of samples in the ordination reflects well the findings described earlier regarding taxa group distribution on different substrates. Further, when correlating the taxa groups (at family level) to the ordination space and abstracting only significant taxa via a Monte Carlo test, there was significant correlation as shown in Fig.6.10b.

Groups that strongly correlated to the leaf pack and root samples were the caddisflies Lepidostomatidae, Hydroptilidae, Leptoceridae and non-biting midges Chironomidae. Taxa highly related to moss samples were true flies Simuliidae, Tabanidae, Tipulidae, the water bug Veliidae, the stonefly Nemouridae, the caddis flies Brachycentridae and Hydropsychidae, and the may flies Baetidae and Heptageniidae.

(a)



(b)

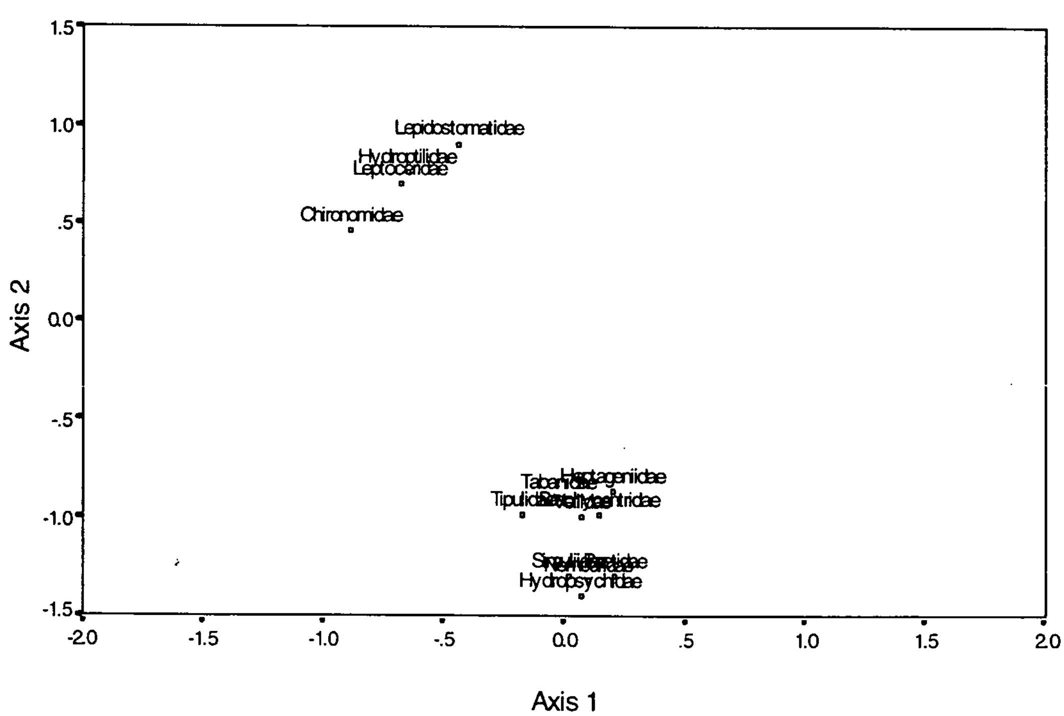


Figure 6.10 Ordination results by HMDS (a) sample ordination (stress 0.0886), and (b) significant taxa groups correlating to the ordination space

(4) Important findings

Significant findings from this study are as follows:

1. Benthic invertebrate assemblages vary between substrate types. The two nutrient-enriched substrate types, namely weed roots and leaf packs, had a greater abundance of benthic species than moss and bare rock substrates.

2. The living hydrophyte root substrate was a notably important habitat for mixed species aggregates, at a range of nymphal development stages.

3. The dead leaf pack substrate was particularly rich in species, and was favoured by caddis species and dipteran midges.

4. At an ordinal level, the most preferred substrate associations were as follows; hydrophyte roots=Trichoptera and Odonata, mosses=Coleoptera and Hemiptera, bedrock=Ephemeroptera, leaf packs=Diptera.

5. The results suggest that the degree to which each habitat will be colonised by any species is dependent on its habitat-specific needs and the development stage in its life-cycle. There is rarely a species found living in a certain situation while another related species occupies that same habitat. At an early larval stage, a species may colonise a particular habitat substrate and then move to another substrate in the later instars, e.g. due to a change in their food demands.

6. Two substrate types, vascular roots and leaf packs, were commonly colonised by the same species, especially the larvae of several caddisfly species.

7. The moss substrate tended to be a characteristic substrate for certain species such as *Laccobius* sp, *Simulium* sp., *Microvelia* sp. and *Pseudovelia* sp., *Nemoura* sp. and *Micrasema* sp.

8. Elucidation of the relationships between benthic species and substrate-nutrients showed that (i) the distribution of benthic species over biotopes is not random but strongly influenced by food source, and (ii) distribution pattern of benthic communities is dependent on species-specific habitat.

A key question, addressed in the next section, is whether it is possible to describe the benthic communities without targeting the various substrate/nutrient habitats directly. Is the riffle and pool system within the stream channel, which is readily accessible, likely to be a reliable source of community data?

It should be noted here that the functional feeding group (FFG) approach was not used to analyse data, or as an *a priori* context in which to investigate community structure. Reliability with that approach would be low as there is almost no information available for this region about the types of food ingested at each larval stage in relation to sources (substrates). Larvae may pass through different FFG stages and rigorous analysis of food content in the gut of each specimen should be done before assigning a species into any FFG. Detailed ecological study of each taxa group or species is still required in this region.

Section 5. Benthic taxa in riffle-pool system

(1) Preface

This section investigates the influences of the riffle-pool system upon benthic community structure via site classification. Inter-site and intra-site analyses were made to compare the responses of the various taxa groups.

Site U03, where the riffle and pool areas were uniformly located on bedrock was chosen to examine within-site effects since this eliminated any confounding variation between substrata. The riffle-pool system in site U02 was selected to compare with that of site U03. The major difference between these two sites is the vegetation community, where site U03 is in evergreen forest while site U02 is in a pine-oak-savanna community. This contrast in biomes is an external factor which will help answer the question whether within-site variation is greater than between-site variation in the riffle-pool community.

Assumptions are that (i) if the riffle versus the pool benthic community within a site is different then the multivariate analysis will cluster the samples in discrete patterns, and (ii) if the riffle-pool system was more influential than the external factor (i.e. vegetation type), then the samples between sites should be classified into riffle-pool clusters rather than reflect the vegetation community.

Six randomly placed Surber samples were collected from each of the riffle and pool habitats at sites U02 and U03 in October 1995. All samples were analysed by UPGMA clustering and significant species discriminating sample clusters were tested via using Kruskal-Wallis analysis (non-parametric F test, GSTA option in PATN, $P<0.05$ is applied).

(1) Intra-site comparison between riffle and pool areas

Taxa abundance between riffle and pool habitats was very different (Fig.6.11a). Even when the two habitats had similar species richness (riffles n=19 species, pool n=20 species), the benthic community differed markedly in abundance (riffle n=177 individuals, pool n=55 individuals).

Coleoptera, Diptera, and Trichoptera were the most abundant taxa found in riffle areas, whereas the numbers of Ephemeroptera, Plecoptera and Odonata individuals were approximately the same in the two habitats.

Riffle beetles were very strongly associated with riffles (n=104 species) and only one specimen occurred in pool samples. *Stenelmis* sp. in particular, was completely confined to the riffle zone (n=101 specimens).
Dipteran species also showed a marked contrast in habitat preference and *Bezzia* sp., Chiromidae spp. and *Antocha* sp. were all more abundant in riffle samples.

Mayfly species found only in riffle samples were *Baetis* sp2 and *Habrophlebiodes* sp., while *Leptophlebia* sp., *Nixe* sp., and *Heptagenia* sp. were present only in pool samples.

Most Trichoptera species were more abundant in riffle zones, including *Goera* sp., *Micrasema* sp., *Hydroptila* sp., *Orthotrichia* sp. and *Tinodes* sp. Two slow moving case-caddisfly species *Molanna* sp. and *Lepidostoma* sp., were found in pool samples.

Other species found only in the riffle zone were the stonefly *Nemoura* sp. the dragonfly *Sympetrum* sp. and the moth *Petrophila* sp.

Other taxa which were found mostly in pool samples were the pyralid *Paracymoriza* sp., the alderfly *Chauliodes* sp., the aeshinid *Anaclaeschra* sp., the libelluid *Perithemis* sp., Oligochaeta, the pteronarcyid *Pteronarcella* sp. and the perlid *Neoperla* sp.

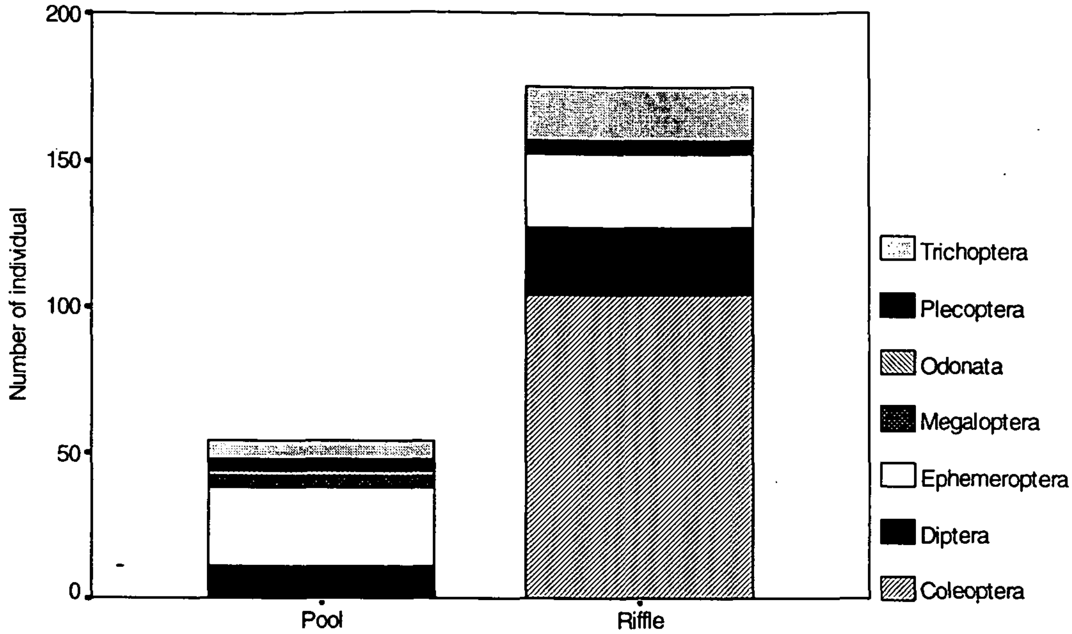
Well-developed species specific preference to either riffle or pool habitats was apparent during sampling at site U03 in October 1995. This is also clear when examining species within the same family; for example, in the mayfly family Leptophlebiidae, all 19 specimens found belonged to two species, *Habrophlebiodes* sp. (10 individuals) and *Letophlebia* sp. (19). The first species was limited to riffle areas while the second species preferred pool reaches. Similarly, with mayfly Baetidae species, all *Baetis* sp2 dwelled on periphyton film in riffle areas whereas *Baetis* sp3 resided in pools of slow-moving water.

Members of the fly family Tipulidae was also characterised by species-habitat specific traits. *Antocha* lived in fast-flowing riffle areas while *Limnophila* sp. aggregations were in pool areas.

The cluster analysis of all riffle and pool samples data by UPGMA, is shown in Fig.6.11b. The samples were clearly grouped into two main groups, the riffles and pools, based on their dissimilar taxa composition.
The significant species identified by Kruskal-Wallis tests as discriminating between the two sample clusters (Fig.6.11b), are *Baetis* sp3 (P=0.0235), *Chauliodes* sp. (P=0.0248), *Leptophlebia* sp. (P=0.0068) and *Stenelmis* sp. (P=0.0001). The last two species are the most important discriminators between these two clusters.

This result supports the notion that the community structure in riffle and pool samples is different. This means that within a site, sampling directed at either riffles or pools, will yield different outcomes.

(a)



(b)

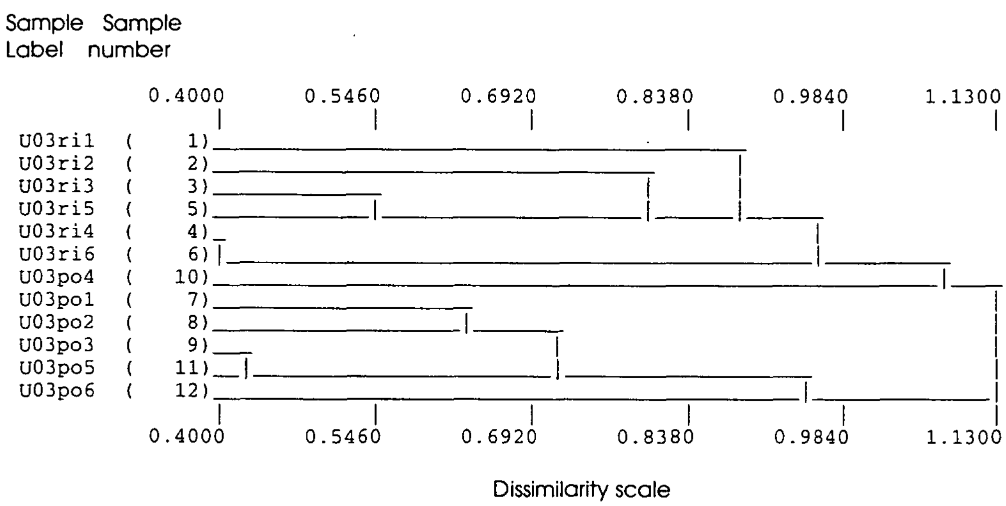


Figure 6.11 Riffle-pool system intra-site analyses (a) taxa abundance composition, and (b) sample clustering by UPGMA in site U03.

Sample labels U03ri1, U03ri2, ...refer to riffle samples of site U03 riffle sample no.1, riffle sample no.2...respectively

Sample labels U03po1, U03po2, ...refer to pool samples of site U03 pool sample no.1, pool sample no.2...respectively

(3) Between-site difference

The clustering of combined riffle and pool samples from sites U02 and U03 (Fig.6.12) clearly highlights the dichotomy between site U02 and U03 clusters.

Furthermore within each site cluster, the samples from riffle (ri) and pool (po) areas were discriminated. Although at site U02, a pair of samples (U02po6 and P02ri3) was clustered separately from adjacent samples, generally the arrangement of samples was the same as site U03, i..e. within-site difference in site U02 is the same as in site U03. Thus, detailed differences between taxa abundance in site U02 will not be described here.

Thus, it can be argued that environmental difference between the sites had a greater influence on the benthic macroinvertebrate community than the within-site internal riffle and pool scale factor.

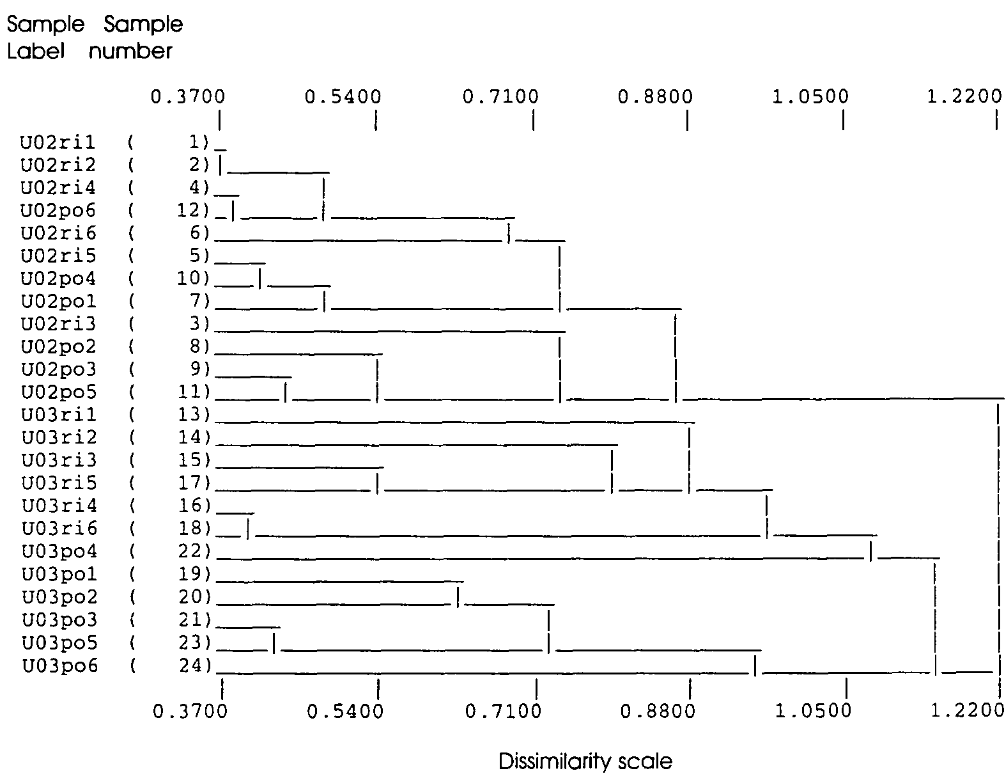


Figure 6.12 Clustering (UPGMA) of riffle and pool samples of site U02 and U03.

(4) Important findings

1. Many benthic larval species are clearly specific to either riffles or pools and many widespread taxa differ in abundance between each system.

2. Between streams in different vegetation biomes, internal variation by riffle-pool system within a site can be overwhelmed by external wider environmental elements (vegetation community and landscape).

3. Sampling using the riffle-pool system can provide certain advantages. Firstly, this system is relatively less complicated and easier to access than multiple small scale microhabitats (section 3). Secondly, comparison between streams in a wider environmental scale (e.g. over the various catchment landscapes) can be effectively made, as the larger scale difference can suppress the internal variation, at least in the example reported here.

Conclusion and discussion

Taxa abundance

Compared to the adjacent Cheon (Chapter 2) and Pong (Chapter 3) catchments, a more diverse benthic species assemblage occupies the pristine stream environment of the Phukradueng National Park. A significant finding is the correlation between trichopteran species richness and the magnitude of the adjacent forest cover of the catchment. This is also apparent in the results from the Cheon catchment (Chapter 3).

The relatively cool year-round temperature is another factor which seems to favour the high caddis species richness in this high catchment. This is also reflected in the Cheon catchment where the cooler stream reaches with densely covered forest have richer caddisfly communities. The dense forest cover contributes more shading to the streams and an input of organic leaf litter as food and case material.

Somewhat surprisingly, only 11 species of mayflies were found in this catchment representing only three families: Baetidae, Heptageniidae and Leptophlebiidae. The characteristic species *Caenis,* which occurs in the lowlands before and after spates, is not found in this elevated catchment. In contrast to the lowlands, heptagenid and leptophlebiid larvae are relatively more abundant in this catchment. These two taxa prefer unpolluted cool water streams. Baetid mayflies are also abundant in this catchment similar to the lowland catchments suggesting that baetids are a widespread group which can occupy various habitat types.

Another diverse taxa group is water beetles with 38 species mostly predaceous diving beetles Dytiscidae, and riffle beetles Elmidae. Dytiscid species are found abundantly in vascular and leaf pack substrates while elmid species colonise moss on boulders and fast-flowing stretches over bedrock.

More detailed studies on each taxa group and species are needed in this headwater catchment. Detailed interrelationships between each species and various environmental factors remain poorly understood. Investigation of the interactions between benthic processes and the whole ecosystem is rarely undertaken due to the associated complexity and cost (Reice and Wohlenberg 1992).

The application of temperate-zone derived principles to tropical ecosystems in the strict sense has limited utility. Knowledge and understanding of the benthic fauna in tropical Asia is still rudimentary. For example, Flowers (1992) and Hildrew and Giller (1994) claimed that benthic animals are relatively less diverse in the tropics than in the temperate zone. However, my findings in this Chapter suggest this is not always true and agree with Yule (1995) who recently reported more diverse macroinvertebrate larvae assemblages in tropical rain forest and rather greater densities than in the temperate zone.

Generalisations about the role of shading are also fraught with exceptions. Hawkins *et al.* (1982) in Oregon and Lester *et al.* (1996) in New Zealand found that macroinvertebrates were more abundant in open streams than in shaded streams. In my study, the greater shading was associated with a more diverse fauna. In this climate, most animals are likely to avoid too much bright, hot sunlight. The blackfly *Simulium* sp. is also widespread in the temperate (Wotton 1992) but in tropical latitudes, it is only found in cool climate streams.

The influence of different substrate size on taxa abundance

There was a strong contrast in species richness and density from sampling in different microhabitats within the same stream site. The bigger substrate sizes (boulders) were found colonised substrates by more benthic species than cobble, pebble, gravel and sand substrates. The effect of substrate size on the benthic species assemblage found by this study is similar to that reported in studies elsewhere (Marchant *et al.* 1985, Quinn and Hickey 1990, Downes *et al.*1993).

The influence of intra-site variation has never been much received attention (Minshall 1984). Most investigators try to avoid within-site differences by sampling only in a particular section of a stream (e.g. riffle). However, the effect of such microhabitat heterogeneity at different microhabitat scale (patchiness) is now receiving overdue attention (Hall *et al.* 1994).

Habitat heterogeneity is important because many species are habitat-specific. This leads to the different benthic larvae abundance on each substrate category. Thus, valid results from comparisons between stream sites will only be achieved with careful sampling design, particularly if benthic macroinvertebrates are to be used as a tool for impact analysis.

Different substrates as preferred food sources

The study finds that many benthic taxa groups colonise selectively in relation to particular biotopes. The hydrophyte vascular root is the most significant microhabitat which attracts diverse benthic taxa. Leaf pack and bryophyte are other important biotopes which support diverse benthic assemblages but to a lesser extent than edge-water weed roots.

The question of whether benthic macroinvertebrate larvae choose certain microhabitats as a food source or shelter is revealed by this study. It is for foraging rather than shelter. Richardson (1992) also found the same result but only analysed leaf packs. Corkum (1992) found low benthic species diversity in streams with lesser amounts of leaf litter.

However, some species colonise concurrently in two different substrates almost in equal numbers (e.g. some species of mayflies and caddisflies occurred both in leaf packs and roots). Possibly, if only limited leaf litter is available then some species may shift to another microhabitat. Thus, lesser amounts of leaf litter may not be the major factor in lessening benthic taxa abundance.

Moss is another food-related substrate. Suren and Winterbourn (1992) found that moss is acting as food source rather than as shelter, although Bryophytes proliferating on stable boulders and bedrock are preferred refuge for certain macroinvertebrates. This study suggests that the moss selected preferentially by certain fauna such as water bugs.

In addition to physical substrate factors, the biotope at a site is another significant factor in conditioning the distribution of benthic taxa.

Riffle and pool system

The riffle and pool system affects the magnitude of benthic taxa colonisation. Species richness and density are very different in these two scales, with some species more abundant in riffle areas while others are plentiful in pools.

Strong contrast in taxa richness and density in riffle-pool systems are also documented by other authors (Barmuta 1990, Richardson 1992).

Few studies to date have investigated the difference between species colonising in riffles and pools system. However, some publications, although not directly dealing with riffle and pool areas imply some facts about benthic species in riffles which are similar to the results reported here. For example, Dudgeon (1996) found that Leptophlebiidae in Hong Kong streams prefer to live in riffle areas, and Rundle *et al.*(1993) reported several mayfly species in riffle zones in the Himalayas, Nepal.
Colonisation of riffle areas by Hydropsychidae pupa was also found by Voelz and Ward (1996).

Even Minshall (1984) emphasises differences of benthic larvae between riffle and pool areas. Investigation of the riffle and pool has highlighted as important in stream classification methods (Hawkins *et al.* 1993).

Lastly, the most striking finding by this study is that internal variation by riffle and pool samples in a stream is less significant than between streams. This suggests the possibility of using just the riffle and pool system to assess water resources in this catchment. This method may be more advantageous than the multiple scale approach, which has to collect mixed samples from boulder, cobble, pebble, gravel and sand or roots, leaf pack and moss systems, and needs considerable time and costs. However, the second approach is still valuable for studies into detailed aquatic ecological processes.

CHAPTER 7

Final Conclusion and Recommendation

Overall summary

1 The benthic macroinvertebrate community varies through time and space across the landscape of the Pong river catchment in northeast Thailand. This variation, when explored via multivariate analyses, could be summarised onto that typical of pollution-impacted sites and less impacted sites. Within the Cheon headwater catchment (Chapter 2), the consequences of land clearing are a major cause which reduces the diversity of benthic species. This effect is especially apparent when comparing benthic taxa abundance of such impacted streams to adjacent streams (reference sites) in conservation forest land.

2 The single presence and absence of certain benthic species at a site can also reflect the magnitude of environmental impact. Certain caddisfly and mayfly species are sensitive to environmental changes caused by human impacts. Native trichopteran species richness and abundance in particular is indicative of the condition of forest lands including pristine forest environments which have the most abundant and diverse caddisfly fauna.

3 In the catchment-wide scale study in the Pong (Chapter 3), there was marked variation in benthic macroinvertebrates both at community and species level across the catchment. The intensity of external effects changes seasonally. Natural events such as spate can override the effect of human impacts during the monsoon period, but during summer months human influences on the benthic community can be very apparent in some places.

4 Water quality declines which subsequently reduce benthic diversity are most apparent during the summer months. Organic pollutants discharged from a large city cause a dramatic reduction in macroinvertebrate species; only the dipterans Chironomidae and *Chaoborus* sp. tolerate these conditions very well.

5 Various multimetric indices and score systems were tested in the Pong catchment, and several were appropriate for use in this region (Chapter 4). Among the fundamental measures, species and family richness were the most reliable statistic which reflected environmental changes. The Ephemeroptera, Plecoptera and Trichoptera (EPT) index was also valuable and reflected water pollution well, particularly dissolved oxygen (DO) and biological oxygen demand (BOD). The Shannon-Weiner index also responded well to variation of DO and BOD. Changes in BOD and DO can

also be effectively detected by the BMWP/ASPT score system. The study results further suggested that among the score systems, the BMWP/ASPT is the most promising for possible use in this region.

6 The question of whether we can use simplified qualitative-type data, i.e. edge-water samples, for assessing water quality was also resolved (Chapter 4). However, this data was less reliable in detecting water pollution in this catchment. Thus an attempt to reduce time and cost by using edge-water sampling instead of the quantitative method failed in this instance. Nevertheless, this question was investigated only in lowland catchment waters which are largely disturbed, while in pristine headwaters (e.g. Phukradueng catchment) this approach might be valid, as the study found a greater diversity of benthic fauna in edge-water weed roots.

7 An attempt to reduce time and cost was further made by investigating the utility of binary (presence and absence (P/A)) data, and also to determine the simplest taxonomic resolution that will yield reliable results (Chapter 5). The study found that at genus or species level the binary data is very reliable, almost to the same extent as density data. Family level data, on the other hand, was only useful with density counts, but only generated a rough indication of water impact. The family binary data did not show any valid relationship to water pollution when analysed.

8 The nature of the benthic community structure in a pristine tropical Asian forest was summarised in Chapter 6. The question of whether a tropical benthic fauna is more or less diverse than the temperate zone fauna was resolved in the case of the elevated Phukradueng catchment where a virgin tropical forest supported the highest diversity of benthic fauna.

9 Chapter 6 addressed the effects of microhabitat scale on the fauna. The magnitude of benthic larva colonisation differed in relation to different substrate sizes. In rainforest streams, the larger the substrate particle size, the greater the diversity of benthic species present.

10 An effect of substrate as a food source was also found when comparing benthic community between bare bedrock (control), moss, leaf pack and edge-water vascular roots. More species were found in root and leaf pack substrates which suggests the importance of the substrate as a food source rather than as shelter. The study also identified a role for species-specific habitat choice in determining small scale distribution. Some benthic species colonise concurrently on more than one substrate type.

11 The last study was about the relationship of the benthic fauna to adjacent riffle and pool areas. The study found that benthic

community structure in each area (small reach) within a stream can be markedly different; but the benthic community variation between riffle and pool is less than that due to wider environmental effects such as forest vegetation type. In other words, the larger scale ecosystem differences dominate the influence of small scale habitat difference.

12 Finally, the results in Chapter 2 to 5 confirm the general feasibility of using benthic macroinvertebrates as indicator taxa for environmental impacts, using contemporary analysis methods. However, further studies are still necessary in other catchments in Thailand and over southeast Asia more generally. Clarification of the relationships between benthic species and habitats requires much more research to be undertaken. Research areas include benthic larval taxonomy, detailed life cycle analysis species and community interaction, functional feeding behaviour and species-habitat associations.

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FIELD RECORD SHEET

Sampling date	Time (24 hr)
Location code	Site name

Weather

Rain	None	Showers	Heavy rain	Last 24 hr	Past week
Cloud cover	None or little	Variable	Extensive		

Weather description on sampling date (e.g., sunny, humid etc.)

Apparent water condition

Approx. mid-stream width (m)-------------------- Approx. mid-stream depth (m)----------------
Mean velocity (m/sec)--------------

Colour	Uncoloured	Coloured			
Odour	Absent	Present	NH3	HS	Other
Visibility	Clear	Good	Fair	Poor	
Floaming	None	Detergent	Surface spot		Scum

Dominant substratum type

Bedrock	Boulder	Cobble	Pebble	Gravel
Sand	Silt/clay			

Aquatic plant

Mosses	Emergent plant
Submerged plants	Marginal plants
Floating	

Riparian vegetation (describe details of types, width etc.)

Approximate canopy shading on stream (%)--

Algae abundance

On substrate	Low	Medium	High---→Dominant algal type----------------
In water column	Low	Medium	High---→Dominant algal type----------------

(dominant algal types e.g., filamentous, unicellular)

Appendix 2.1 (cont.)

Water physicochemistry variables (measured in the field)

Variable	Sample no.					
	1	2	3	4	5	6
Water temp. (°C)						
pH						
DO (mg/L)						
Sat.DO (%)						
EC (μS/cm)						
TDS (mg/L)						

Sketch sampling site(indicates sampling units, point-source discharge, and immediate environment)

Additional notes

Appendix 2.2 Macroinvertebrate species list of the Cheon catchment

Order	Family	Species
Coleoptera	Curculionidae	Stenopelmus sp.
	Dytiscidae	Cybister sp.
		Deronectes sp.
		Hyphydrus sp.
		Neptostemus sp.
	Elmidae	Cleptelmis sp.
		Hexacylloepus sp.
		Stenelmis sp.
	Gyrinidae	Dineutus sp.
	Hydrophilidae	Berosus sp.
		Enochrus sp.
		Hydrochus sp.
		Hydrophilidae sp1
		Laccobius sp.
	Psephenidae	Eubrianax sp.
Decapoda	Palaemonidae	Macrobrachium lanchesteri
Diptera	Athericidae	Atrichops sp.
	Ceratopogonidae	Bezzia sp.
	Chironomidae	Chironomidae spp.
	Culicidae	Mimomyia sp.
	Muscidae	Limnophora sp.
	Rhagionidae	Atherix sp.
	Simuliidae	Simulium sp.
	Tabanidae	Tabanidae sp1
	Tipulidae	Antocha sp.
		Hexatoma sp.
		Limnophila sp.
Ephemeroptera	Baetidae	Baetis sp1
		Baetis sp2
		Baetis sp3
		Centroptilum sp.
		Pseudocloeon sp.
	Caenidae	Caenis sp1
	Ephemeridae	Ephemera sp.
		Litobrancha sp.
	Heptageniidae	Heptagenia sp.
	Leptophlebiidae	Choroterpes sp.
		Habrophlebiodes sp.
		Leptophlebia sp.
		Paraleptophlebia sp.
		Thraulodes sp.
	Polymitarcyidae	Campsurus sp.
	Potamanthidae	Potamanthus sp.
	Siphlonuridae	Siphlonurus sp.
Hemiptera	Aphelocheiridae	Aphelocheirus sp.
	Belostomatidae	Sphaerodema sp.
	Corixidae	Hesperocorixa sp.
		Morphocorixa sp.
		Sigara sp.
		Tenagobia sp.
	Gerridae	Metrobates sp.
		Rhyacobates sp.

Appendix 2.2 (cont.)

Order	Family	Species
Lepidoptera	Pyralidae	Petrophila sp.
Megaloptera	Corydalidae	Neochauliodes sp.
	Sialidae	Sialis sp.
Mesogastropoda	Viviparidae	Mekongia sp.
		Melanoides tuberculata
Odonata	Aeshnidae	Aeschnophlebia sp.
		Oplonaeschna sp.
	Coenagrionidae	Argiocnemis sp.
	Gomphidae	Dromogomphus sp.
		Erpetogomphus sp.
		Hagenius sp.
		Labrogomphus sp.
		Progomphus sp.
		Shogomphus sp.
		Sinogomphus sp.
	Libellulidae	Diplacodes sp.
		Libellulidae sp1
	Macromiidae	Macromia sp.
	Platycnemididae	Copera marginipes
		Platycnemididae sp1
Oligochaeta	Oligochaeta	Oligochaeta
Plecoptera	Perlidae	Neoperla sp.
		Phanoperla sp.
Trichoptera	Calamoceratidae	Anisocentropus sp.
	Ecnomidae	Ecnomus sp.
	Goeridae	Goera sp.
	Hydropsychidae	Amphipsyche meridiana
		Ceratopsyche sp.
		Cheumatopsyche malaysiensis
		Hydropsyche sp.
		Macrostemum similior
		Synaptopsyche klakahana
	Hydroptilidae	Hydroptila sp.
		Oxyethira sp.
	Leptoceridae	Triaenodes sp.
	Molannidae	Molanna sp.
	Odontoceridae	Marilia sp.
		Namamyia sp.
	Philopotamidae	Chimarra sp.
	Phryganeidae	Oligostomis sp.
	Polycentropodidae	Neureclipsis sp.
		Phylocentropus sp.
		Polycentropus sp.
		Pseudoneureclipsis sp.
	Psychomyiidae	Tinodes sp.
	Stenopsychidae	Stenopsyche siamensis
Veneroida	Corbiculidae	Corbicula blandina

Appendix 2.3 Macroinvertebrate individuals sampled from the Cheon headwater catchment (October 1995-August 1996)

(Numbers attached to the site code: 1=Oct, 2=Dec 1995; 3=Feb, 4=Apr, 5=Jun, 6=Aug 1996)

Site Code	Order	Family	Species	Replicate no.						Total
				1	2	3	4	5	6	
A1	Diptera	Chironomidae	Chironomidae spp.	0	0	0	0	2	2	4
A1	Diptera	Tipulidae	Hexatoma sp.	0	1	1	1	0	1	4
A1	Ephemeroptera	Baetidae	Baetis sp.2	0	0	0	1	0	0	1
A1	Ephemeroptera	Caenidae	Caenis sp.1	1	2	0	0	0	1	4
A1	Ephemeroptera	Heptageniidae	Heptagenia sp.	0	0	0	1	0	0	1
A1	Odonata	Gomphidae	Erpetogomphus sp.	0	0	0	1	0	1	2
A1	Plecoptera	Perlidae	Neoperla sp.	0	0	1	0	0	0	1
A1	Trichoptera	Ecnomidae	Ecnomus sp.	0	0	0	0	0	1	1
A1	Trichoptera	Hydropsychidae	Hydropsyche sp.	0	1	0	0	0	0	1
B1	Coleoptera	Hydrophilidae	Hydrochus sp.	0	1	0	0	0	0	1
B1	Decapoda	Palaemonidae	Macrobrachium lanchesteri	0	0	1	0	0	0	1
B1	Diptera	Chironomidae	Chironomidae spp.	16	12	18	17	3	7	73
B1	Ephemeroptera	Baetidae	Baetis sp.2	0	0	1	0	0	0	1
B1	Ephemeroptera	Leptophlebiidae	Habrophlebiodes sp.	0	2	1	0	0	0	3
B1	Hemiptera	Gerridae	Metrobates sp.	0	0	0	0	1	0	1
C1	Coleoptera	Dytiscidae	Cybister sp.	0	0	0	0	1	1	2
C1	Coleoptera	Elmidae	Hexacylloepus sp.	1	0	0	0	0	0	1
C1	Decapoda	Palaemonidae	Macrobrachium lanchesteri	0	0	0	1	0	0	1
C1	Diptera	Chironomidae	Chironomidae spp.	0	0	1	0	2	2	5
C1	Diptera	Tabanidae	Tabanidae sp.1	0	0	1	0	0	0	1
C1	Ephemeroptera	Baetidae	Baetis sp.2	0	0	0	1	0	0	1
C1	Ephemeroptera	Caenidae	Caenis sp.1	0	0	1	1	2	2	6
C1	Ephemeroptera	Polymitarcyidae	Campsurus sp.	0	1	2	0	0	0	3
C1	Ephemeroptera	Leptophlebiidae	Habrophlebiodes sp.	2	0	1	1	3	3	10
C1	Megaloptera	Sialidae	Sialis sp.	1	1	1	0	0	0	3
C1	Odonata	Gomphidae	Dromogomphus sp.	1	0	0	0	0	0	1
C1	Odonata	Gomphidae	Hagenius sp.	0	0	1	0	0	0	1
C1	Trichoptera	Hydropsychidae	Cheumatopsyche malaysiensis	1	0	0	0	0	0	1
C1	Trichoptera	Odontoceridae	Namamyia sp.	1	0	0	0	0	0	1
D1	Coleoptera	Psephenidae	Eubrianax sp.	0	0	0	1	0	0	1
D1	Coleoptera	Elmidae	Hexacylloepus sp.	0	0	0	0	0	1	1
D1	Coleoptera	Hydrophilidae	Hydrophilidae sp.1	0	1	0	0	0	0	1
D1	Diptera	Chironomidae	Chironomidae spp.	3	2	0	1	0	1	7
D1	Ephemeroptera	Baetidae	Baetis sp.2	3	0	0	0	6	1	10
D1	Ephemeroptera	Baetidae	Baetis sp.3	1	0	0	0	1	0	2
D1	Ephemeroptera	Caenidae	Caenis sp.1	0	1	0	1	0	0	2
D1	Ephemeroptera	Ephemeridae	Ephemera sp.	11	1	1	3	0	5	21
D1	Ephemeroptera	Leptophlebiidae	Habrophlebiodes sp.	0	1	4	1	0	1	7
D1	Lepidoptera	Pyralidae	Petrophila sp.	0	0	0	0	1	0	1
D1	Mesogastropoda	Viviparidae	Mekongia sp.	0	0	0	1	0	0	1
D1	Odonata	Gomphidae	Erpetogomphus sp.	0	1	0	0	0	0	1
D1	Odonata	Libellulidae	Libellulidae sp.1	0	0	1	0	0	0	1
D1	Odonata	Platycnemididae	Platycnemididae sp.1	1	0	0	0	0	0	1
D1	Trichoptera	Odontoceridae	Namamyia sp.	0	0	0	2	0	0	2
E1	Coleoptera	Elmidae	Stenelmis sp.	1	0	0	0	0	0	1
E1	Coleoptera	Curculionidae	Stenopelmus sp.	0	0	0	0	1	0	1

Appendix 2.3 (cont.)

Site Code	Order	Family	Species	Replicate no.						Total
				1	2	3	4	5	6	
E1	Diptera	Chironomidae	Chironomidae spp.	1	1	0	1	2	0	5
E1	Mesogastropoda	Viviparidae	Melanoides tuberculata	1	0	0	0	0	0	1
E1	Oligochaeta	Oligochaeta	Oligochaeta	10	17	12	8	8	13	68
E1	Veneroida	Corbiculidae	Corbicula blandina	1	0	0	0	1	0	2
F1	Diptera	Ceratopogonidae	Bezzia sp.	0	0	0	1	0	0	1
F1	Diptera	Chironomidae	Chironomidae spp.	1	2	2	0	8	12	25
F1	Diptera	Tipulidae	Hexatoma sp.	0	1	0	0	0	0	1
F1	Mesogastropoda	Viviparidae	Melanoides tuberculata	0	0	0	1	0	0	1
F1	Oligochaeta	Oligochaeta	Oligochaeta	11	3	5	18	8	0	45
F1	Veneroida	Corbiculidae	Corbicula blandina	0	0	0	0	1	0	1
A2	Coleoptera	Elmidae	Cleptelmis sp.	0	0	0	0	2	0	2
A2	Diptera	Chironomidae	Chironomidae spp.	154	0	59	21	27	5	266
A2	Diptera	Tipulidae	Limnophila sp.	3	0	0	4	3	4	14
A2	Ephemeroptera	Baetidae	Baetis sp.2	7	0	3	1	3	2	16
A2	Ephemeroptera	Caenidae	Caenis sp.1	1	0	1	0	3	0	5
A2	Ephemeroptera	Leptophlebiidae	Habrophlebiodes sp.	2	0	0	0	0	0	2
A2	Ephemeroptera	Siphlonuridae	Siphlonurus sp.	1	0	0	0	0	0	1
A2	Odonata	Gomphidae	Erpetogomphus sp.	0	0	2	2	2	1	7
A2	Odonata	Gomphidae	Labrogomphus sp.	1	0	0	0	0	0	1
A2	Trichoptera	Hydropsychidae	Amphipsyche meridiana	11	0	4	0	0	0	15
A2	Trichoptera	Hydropsychidae	Cheumatopsyche malaysiensis	165	0	216	11	63	12	467
A2	Trichoptera	Ecnomidae	Ecnomus sp.	1	0	0	0	0	0	1
A2	Trichoptera	Hydroptilidae	Hydroptila sp.	1	0	0	0	0	0	1
A2	Trichoptera	Hydropsychidae	Macrostemum similior	4	0	3	0	0	0	7
A2	Trichoptera	Hydropsychidae	Synaptopsyche klakahana	107	0	0	0	0	0	107
B2	Coleoptera	Dytiscidae	Hyphydrus sp.	2	1	0	0	0	0	3
B2	Decapoda	Palaemonidae	Macrobrachium lanchesteri	2	0	0	0	0	0	2
B2	Diptera	Ceratopogonidae	Bezzia sp.	0	0	2	0	1	0	3
B2	Diptera	Chironomidae	Chironomidae spp.	0	1	2	2	3	0	8
B2	Ephemeroptera	Baetidae	Baetis sp.1	0	0	3	2	1	5	11
B2	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	0	0	1	2	0	4	7
B2	Megaloptera	Sialidae	Sialis sp.	1	2	0	1	0	0	4
B2	Odonata	Macromiidae	Macromia sp.	1	2	0	1	1	0	5
B2	Trichoptera	Philopotamidae	Chimarra sp.	1	1	0	0	1	0	3
B2	Trichoptera	Phryganeidae	Oligostomis sp.	1	0	0	0	0	1	2
C2	Coleoptera	Hydrophilidae	Berosus sp.	0	1	0	0	0	1	2
C2	Coleoptera	Psephenidae	Eubrianax sp.	6	1	6	0	4	0	17
C2	Diptera	Rhagionidae	Atherix sp.	1	5	3	3	0	1	13
C2	Diptera	Ceratopogonidae	Bezzia sp.	1	2	0	1	0	1	5
C2	Diptera	Chironomidae	Chironomidae spp.	123	10	58	11	4	12	218
C2	Diptera	Tipulidae	Limnophila sp.	0	2	0	1	0	1	4
C2	Diptera	Culicidae	Mimomyia sp.	0	1	0	0	1	1	3
C2	Ephemeroptera	Baetidae	Baetis sp.1	4	1	0	0	1	8	14
C2	Ephemeroptera	Caenidae	Caenis sp.1	13	6	4	0	2	4	29
C2	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	2	0	14	0	0	1	17
C2	Ephemeroptera	Ephemeridae	Ephemera sp.	13	5	4	3	2	4	31
C2	Ephemeroptera	Heptageniidae	Heptagenia sp.	2	0	4	0	0	0	6
C2	Ephemeroptera	Ephemeridae	Litobrancha sp.	4	5	0	3	0	4	16
C2	Hemiptera	Gerridae	Rhyacobates sp.	0	2	1	0	2	0	5

Appendix 2.3 (cont.)

Site Code	Order	Family	Species	Replicate no. 1	2	3	4	5	6	Total
C2	Hemiptera	Corixidae	Tenagobia sp.	0	2	1	0	0	1	4
C2	Megaloptera	Sialidae	Sialis sp.	4	1	4	1	2	0	12
C2	Odonata	Coenagrionidae	Argiocnemis sp.	2	1	4	1	2	0	10
C2	Odonata	Libellulidae	Diplacodes sp.	1	1	4	0	3	4	13
C2	Odonata	Gomphidae	Erpetogomphus sp.	2	1	2	1	2	2	10
C2	Odonata	Macromiidae	Macromia sp.	1	2	0	0	4	4	11
C2	Odonata	Gomphidae	Sinogomphus sp.	2	2	2	1	2	0	9
C2	Oligochaeta	Oligochaeta	Oligochaeta	0	1	4	24	3	10	42
C2	Trichoptera	Calamoceratidae	Anisocentropus sp.	4	1	18	24	0	10	57
C2	Trichoptera	Philopotamidae	Chimarra sp.	2	0	2	0	0	0	4
C2	Trichoptera	Ecnomidae	Ecnomus sp.	1	0	0	0	1	2	4
C2	Trichoptera	Goeridae	Goera sp.	0	0	0	0	0	2	2
C2	Trichoptera	Hydroptilidae	Oxyethira sp.	4	1	2	0	0	0	7
C2	Trichoptera	Polycentropodidae	Phylocentropus sp.	1	0	0	0	1	0	2
D2	Diptera	Rhagionidae	Atherix sp.	0	1	5	0	1	1	8
D2	Diptera	Chironomidae	Chironomidae spp.	10	7	10	33	9	10	79
D2	Ephemeroptera	Baetidae	Baetis sp.1	0	0	0	0	0	1	1
D2	Ephemeroptera	Baetidae	Baetis sp.2	0	0	0	0	1	0	1
D2	Ephemeroptera	Caenidae	Caenis sp.1	2	4	2	2	2	0	12
D2	Ephemeroptera	Ephemeridae	Ephemera sp.	2	26	27	2	2	12	71
D2	Ephemeroptera	Heptagenidae	Heptagenia sp.	32	2	27	1	4	2	68
D2	Hemiptera	Gerridae	Rhyacobates sp.	0	2	1	0	0	0	3
D2	Hemiptera	Corixidae	Tenagobia sp.	0	1	0	1	4	2	8
D2	Odonata	Macromiidae	Macromia sp.	0	1	0	0	0	2	3
D2	Odonata	Gomphidae	Progomphus sp.	1	1	1	0	0	0	3
D2	Oligochaeta	Oligochaeta	Oligochaeta	1	2	0	0	0	2	5
D2	Trichoptera	Ecnomidae	Ecnomus sp.	1	2	0	0	0	2	5
E2	Diptera	Ceratopogonidae	Bezzia sp.	1	2	8	1	2	2	16
E2	Diptera	Chironomidae	Chironomidae spp.	18	7	15	20	16	7	83
E2	Ephemeroptera	Caenidae	Caenis sp.1	1	0	2	1	0	0	4
E2	Ephemeroptera	Ephemeridae	Ephemera sp.	0	2	2	0	0	0	4
E2	Oligochaeta	Oligochaeta	Oligochaeta	42	3	9	40	0	22	116
E2	Plecoptera	Perlidae	Neoperla sp.	42	3	9	1	0	22	77
E2	Plecoptera	Perlidae	Phanoperla sp.	0	0	0	1	0	0	1
E2	Trichoptera	Polycentropodidae	Phylocentropus sp.	0	0	0	1	0	0	1
F2	Coleoptera	Psephenidae	Eubrianax sp.	0	0	0	1	0	1	2
F2	Diptera	Ceratopogonidae	Bezzia sp.	0	1	0	2	0	0	3
F2	Diptera	Chironomidae	Chironomidae spp.	0	1	0	6	0	1	8
F2	Ephemeroptera	Ephemeridae	Litobrancha sp.	0	3	3	2	0	2	10
F2	Oligochaeta	Oligochaeta	Oligochaeta	0	3	3	1	0	2	9
A3	Coleoptera	Hydrophilidae	Hydrophilidae sp.1	0	0	0	0	3	1	4
A3	Coleoptera	Elmidae	Stenelmis sp.	0	0	0	3	1	0	4
A3	Decapoda	Palaemonidae	Macrobrachium lanchesteri	1	2	0	1	0	0	4
A3	Diptera	Rhagionidae	Atherix sp.	1	0	0	4	0	1	6
A3	Diptera	Ceratopogonidae	Bezzia sp.	0	0	1	0	0	0	1
A3	Diptera	Chironomidae	Chironomidae spp.	7	8	0	5	3	0	23
A3	Diptera	Tipulidae	Limnophila sp.	2	0	0	0	0	0	2
A3	Ephemeroptera	Baetidae	Baetis sp.1	2	2	0	0	0	8	12
A3	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	1	1	0	3	0	0	5

Appendix 2.3 (cont.)

Site Code	Order	Family	Species	Replicate no.						Total
				1	2	3	4	5	6	
A3	Ephemeroptera	Ephemeridae	Ephemera sp.	2	0	0	0	0	0	2
A3	Ephemeroptera	Heptageniidae	Heptagenia sp.	0	0	1	0	0	2	3
A3	Ephemeroptera	Potamanthidae	Potamanthus sp.	1	4	22	24	19	17	87
A3	Odonata	Gomphidae	Labrogomphus sp.	0	1	1	12	4	0	18
A3	Trichoptera	Calamoceratidae	Anisocentropus sp.	0	0	0	0	1	0	1
A3	Trichoptera	Hydropsychidae	Cheumatopsyche malaysiensis	1	1	9	17	0	0	28
A3	Trichoptera	Philopotamidae	Chimarra sp.	0	1	8	1	0	0	10
A3	Trichoptera	Ecnomidae	Ecnomus sp.	0	0	2	2	0	0	4
A3	Trichoptera	Hydropsychidae	Macrostemum similior	0	0	0	0	18	0	18
A3	Trichoptera	Polycentropodidae	Neureclipsis sp.	1	0	0	0	0	0	1
A3	Trichoptera	Polycentropodidae	Phylocentropus sp.	0	2	0	0	0	5	7
A3	Trichoptera	Polycentropodidae	Polycentropus sp.	1	0	4	9	20	0	34
B3	Coleoptera	Elmidae	Stenelmis sp.	0	1	1	0	0	0	2
B3	Diptera	Chironomidae	Chironomidae spp.	0	0	2	0	0	0	2
B3	Ephemeroptera	Baetidae	Baetis sp.1	0	0	2	0	1	1	4
B3	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	0	0	0	0	1	0	1
B3	Megaloptera	Sialidae	Sialis sp.	0	0	2	0	0	5	7
B3	Odonata	Gomphidae	Sinogomphus sp.	1	1	0	6	7	0	15
C3	Coleoptera	Psephenidae	Eubrianax sp.	0	0	0	0	0	1	1
C3	Coleoptera	Elmidae	Stenelmis sp.	1	0	0	0	2	0	3
C3	Diptera	Rhagionidae	Atherix sp.	4	1	0	0	0	0	5
C3	Diptera	Ceratopogonidae	Bezzia sp.	0	0	2	17	3	1	23
C3	Diptera	Chironomidae	Chironomidae spp.	185	8	34	1	51	6	285
C3	Diptera	Tipulidae	Limnophila sp.	0	0	1	0	0	0	1
C3	Diptera	Culicidae	Mimomyia sp.	0	1	0	0	0	0	1
C3	Ephemeroptera	Baetidae	Baetis sp.1	0	0	1	0	7	0	8
C3	Ephemeroptera	Caenidae	Caenis sp.1	0	1	0	0	9	0	10
C3	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	0	0	32	2	0	0	34
C3	Hemiptera	Corixidae	Sigara sp.	0	0	0	0	2	0	2
C3	Hemiptera	Corixidae	Tenagobia sp.	1	1	0	0	0	0	2
C3	Megaloptera	Sialidae	Sialis sp.	0	1	1	0	0	2	4
C3	Odonata	Aeshnidae	Aeschnophlebia sp.	0	0	1	0	1	0	2
C3	Odonata	Coenagrionidae	Argiocnemis sp.	8	7	0	0	1	3	19
C3	Odonata	Libellulidae	Diplacodes sp.	0	0	10	1	1	0	12
C3	Odonata	Gomphidae	Erpetogomphus sp.	0	0	0	1	2	0	3
C3	Trichoptera	Calamoceratidae	Anisocentropus sp.	0	0	0	0	1	0	1
C3	Trichoptera	Ecnomidae	Ecnomus sp.	0	0	10	4	1	0	15
C3	Trichoptera	Polycentropodidae	Polycentropus sp.	1	4	0	0	0	0	5
C3	Trichoptera	Leptoceridae	Triaenodes sp.	2	0	0	0	0	0	2
E3	Coleoptera	Elmidae	Stenelmis sp.	4	0	1	1	0	0	6
E3	Diptera	Chironomidae	Chironomidae spp.	12	3	5	3	0	1	24
E3	Diptera	Tipulidae	Limnophila sp.	0	14	8	0	1	13	36
E3	Ephemeroptera	Ephemeridae	Litobrancha sp.	1	1	0	1	0	0	3
E3	Oligochaeta	Oligochaeta	Oligochaeta	62	0	0	23	0	21	106
E3	Veneroida	Corbiculidae	Corbicula blandina	1	42	10	3	65	1	122
F3	Diptera	Ceratopogonidae	Bezzia sp.	0	0	0	0	2	0	2
F3	Diptera	Chironomidae	Chironomidae spp.	3	4	0	4	9	7	27
F3	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	1	0	0	0	2	0	3
F3	Ephemeroptera	Ephemeridae	Litobrancha sp.	1	0	0	0	0	1	2

Appendix 2.3 (cont.)

Site Code	Order	Family	Species	Replicate no.						Total
				1	2	3	4	5	6	
A4	Coleoptera	Elmidae	Cleptelmis sp.	2	1	1	2	0	0	6
A4	Coleoptera	Elmidae	Stenelmis sp.	0	0	0	0	1	0	1
A4	Diptera	Chironomidae	Chironomidae spp.	6	11	34	21	9	19	100
A4	Diptera	Tipulidae	Limnophila sp.	0	0	5	2	1	5	13
A4	Ephemeroptera	Caenidae	Caenis sp.1	0	0	0	0	3	0	3
A4	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	5	3	4	4	1	0	17
A4	Ephemeroptera	Ephemeridae	Ephemera sp.	0	0	1	3	0	1	5
A4	Ephemeroptera	Heptageniidae	Heptagenia sp.	0	0	2	4	1	2	9
A4	Hemiptera	Aphelocheiridae	Aphelocheirus sp.	1	0	0	0	2	0	3
A4	Plecoptera	Perlidae	Phanoperla sp.	1	0	3	0	0	0	4
A4	Trichoptera	Hydropsychidae	Amphipsyche meridiana	2	0	0	0	0	0	2
A4	Trichoptera	Philopotamidae	Chimarra sp.	0	0	0	0	1	3	4
A4	Trichoptera	Ecnomidae	Ecnomus sp.	1	0	0	0	0	0	1
A4	Trichoptera	Goeridae	Goera sp.	0	0	1	0	1	0	2
A4	Trichoptera	Polycentropodidae	Polycentropus sp.	0	4	32	10	2	23	71
A4	Trichoptera	Stenopsychidae	Stenopsyche siamensis	0	0	1	3	0	0	4
A4	Trichoptera	Psychomyiidae	Tinodes sp.	1	0	0	0	7	0	8
B4	Diptera	Chironomidae	Chironomidae spp.	22	0	0	0	0	0	22
B4	Ephemeroptera	Ephemeridae	Ephemera sp.	1	8	1	3	0	2	15
C4	Coleoptera	Dytiscidae	Deronectes sp.	0	1	1	0	0	0	2
C4	Coleoptera	Psephenidae	Eubrianax sp.	3	0	3	0	1	1	8
C4	Diptera	Ceratopogonidae	Bezzia sp.	0	0	0	0	0	1	1
C4	Diptera	Chironomidae	Chironomidae spp.	13	1	12	1	0	2	29
C4	Ephemeroptera	Caenidae	Caenis sp.1	0	0	2	1	0	0	3
C4	Ephemeroptera	Potamanthidae	Potamanthus sp.	1	0	0	0	1	0	2
C4	Odonata	Libellulidae	Diplacodes sp.	0	0	1	0	1	0	2
C4	Odonata	Gomphidae	Sinogomphus sp.	0	0	2	0	0	0	2
C4	Oligochaeta	Oligochaeta	Oligochaeta	3	1	0	0	17	0	21
C4	Trichoptera	Polycentropodidae	Polycentropus sp.	1	0	1	1	1	24	28
E4	Coleoptera	Elmidae	Stenelmis sp.	9	0	4	0	7	5	25
E4	Diptera	Chironomidae	Chironomidae spp.	1	7	0	5	0	0	13
E4	Ephemeroptera	Caenidae	Caenis sp.1	2	4	0	0	0	0	6
E4	Odonata	Gomphidae	Erpetogomphus sp.	0	0	1	0	0	1	2
E4	Oligochaeta	Oligochaeta	Oligochaeta	0	0	0	0	0	1	1
E4	Veneroida	Corbiculidae	Corbicula blandina	1	1	1	1	1	36	41
F4	Diptera	Ceratopogonidae	Bezzia sp.	0	1	0	0	1	0	2
F4	Diptera	Chironomidae	Chironomidae spp.	2	4	1	1	3	1	12
F4	Diptera	Muscidae	Limnophora sp.	0	0	0	0	0	1	1
A5	Coleoptera	Elmidae	Cleptelmis sp.	2	0	0	0	0	0	2
A5	Coleoptera	Psephenidae	Eubrianax sp.	2	0	1	0	1	1	5
A5	Diptera	Rhagionidae	Atherix sp.	1	0	0	0	0	0	1
A5	Diptera	Chironomidae	Chironomidae spp.	1	0	5	1	0	0	7
A5	Diptera	Tipulidae	Limnophila sp.	0	0	0	0	1	1	2
A5	Ephemeroptera	Caenidae	Caenis sp.1	0	0	1	0	1	1	3
A5	Ephemeroptera	Ephemeridae	Ephemera sp.	7	6	4	3	0	0	20
A5	Ephemeroptera	Leptophlebiidae	Thraulodes sp.	0	0	1	0	0	0	1
A5	Hemiptera	Belostomatidae	Sphaerodema sp.	4	3	0	0	0	1	8
A5	Plecoptera	Perlidae	Phanoperla sp.	0	1	1	0	1	0	3
A5	Trichoptera	Hydropsychidae	Cheumatopsyche malaysiensis	0	0	2	2	1	0	5

Appendix 2.3 (cont.)

Site Code	Order	Family	Species	Replicate no.						Total
				1	2	3	4	5	6	
A5	Trichoptera	Goeridae	Goera sp.	1	2	0	0	0	0	3
A5	Trichoptera	Hydropsychidae	Hydropsyche sp.	13	3	2	0	0	0	18
A5	Trichoptera	Polycentropodidae	Neureclipsis sp.	6	0	0	0	0	0	6
A5	Trichoptera	Polycentropodidae	Phylocentropus sp.	0	1	0	0	1	0	2
A5	Trichoptera	Psychomyiidae	Tinodes sp.	0	0	2	2	0	0	4
B5	Megaloptera	Sialidae	Sialis sp.	1	2	2	1	0	1	7
C5	Coleoptera	Hydrophilidae	Enochrus sp.	0	0	0	0	0	1	1
C5	Coleoptera	Psephenidae	Eubrianax sp.	0	0	0	0	1	0	1
C5	Coleoptera	Dytiscidae	Neptostemus sp.	1	0	0	0	1	0	2
C5	Decapoda	Palaemonidae	Macrobrachium lanchesteri	1	0	1	0	0	0	2
C5	Diptera	Athericidae	Atrichops sp.	1	0	0	0	0	0	1
C5	Diptera	Ceratopogonidae	Bezzia sp.	0	1	0	0	3	0	4
C5	Diptera	Chironomidae	Chironomidae spp.	1	6	0	0	1	0	8
C5	Diptera	Tipulidae	Limnophila sp.	0	1	1	0	0	0	2
C5	Ephemeroptera	Caenidae	Caenis sp.1	0	0	0	1	0	5	6
C5	Ephemeroptera	Baetidae	Centroptilum sp.	0	0	1	0	0	0	1
C5	Ephemeroptera	Heptageniidae	Heptagenia sp.	0	0	0	0	1	0	1
C5	Ephemeroptera	Potamanthidae	Potamanthus sp.	0	0	0	0	3	1	4
C5	Ephemeroptera	Baetidae	Pseudocloeon sp.	1	5	0	1	1	0	8
C5	Odonata	Libellulidae	Diplacodes sp.	0	1	0	0	0	0	1
C5	Odonata	Macromiidae	Macromia sp.	3	0	0	0	1	3	7
C5	Oligochaeta	Oligochaeta	Oligochaeta	0	0	0	0	1	0	1
C5	Trichoptera	Ecnomidae	Ecnomus sp.	0	1	0	1	0	0	2
C5	Trichoptera	Leptoceridae	Triaenodes sp.	1	0	0	0	0	0	1
C5	Veneroida	Corbiculidae	Corbicula blandina	0	0	7	0	3	0	10
D5	Coleoptera	Elmidae	Cleptelmis sp.	0	1	1	0	2	1	5
D5	Coleoptera	Gyrinidae	Dineutus sp.	1	0	0	1	4	4	10
D5	Coleoptera	Psephenidae	Eubrianax sp.	0	0	2	0	0	0	2
D5	Decapoda	Palaemonidae	Macrobrachium lanchesteri	0	0	1	2	1	0	4
D5	Diptera	Chironomidae	Chironomidae spp.	6	2	14	5	10	2	39
D5	Diptera	Simuliidae	Simulium sp.	6	0	0	8	0	1	15
D5	Ephemeroptera	Caenidae	Caenis sp.1	0	1	15	0	0	4	20
D5	Ephemeroptera	Baetidae	Centroptilum sp.	1	0	0	7	1	2	11
D5	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	3	0	1	0	0	0	4
D5	Ephemeroptera	Ephemeridae	Ephemera sp.	27	11	0	0	10	0	48
D5	Ephemeroptera	Heptageniidae	Heptagenia sp.	5	0	0	18	2	0	25
D5	Ephemeroptera	Leptophlebiidae	Leptophlebia sp.	0	1	0	1	0	0	2
D5	Ephemeroptera	Leptophlebiidae	Paraleptophlebia sp.	0	0	0	1	0	0	1
D5	Ephemeroptera	Leptophlebiidae	Thraulodes sp.	0	0	0	0	0	7	7
D5	Megaloptera	Corydalidae	Neochauliodes sp.	0	0	0	0	2	0	2
D5	Odonata	Platycnemididae	Copera marginipes	0	0	0	0	1	0	1
D5	Odonata	Libellulidae	Diplacodes sp.	0	0	0	0	0	0	0
D5	Odonata	Gomphidae	Erpetogomphus sp.	1	0	0	2	5	0	8
D5	Odonata	Aeshnidae	Oplonaeschna sp.	0	0	0	1	0	1	2
D5	Trichoptera	Calamoceratidae	Anisocentropus sp.	0	1	0	0	2	2	5
D5	Trichoptera	Hydropsychidae	Ceratopsyche sp.	0	0	9	0	0	2	11
D5	Trichoptera	Philopotamidae	Chimarra sp.	1	0	4	0	0	3	8
D5	Trichoptera	Hydroptilidae	Hydroptila sp.	0	0	2	0	1	0	3
D5	Trichoptera	Hydropsychidae	Macrostemum similior	0	0	1	0	0	5	6

Appendix 2.3 (cont.)

Site Code	Order	Family	Species	Replicate no.						Total
				1	2	3	4	5	6	
D5	Trichoptera	Molannidae	Molanna sp.	0	0	1	0	0	0	1
D5	Trichoptera	Hydroptilidae	Oxyethira sp.	0	0	0	0	0	3	3
D5	Trichoptera	Leptoceridae	Triaenodes sp.	0	0	1	0	0	5	6
E5	Diptera	Ceratopogonidae	Bezzia sp.	1	1	0	0	1	1	4
E5	Diptera	Chironomidae	Chironomidae spp.	0	2	0	0	0	3	5
E5	Oligochaeta	Oligochaeta	Oligochaeta	0	0	0	15	0	0	15
E5	Veneroida	Corbiculidae	Corbicula blandina	21	4	18	0	11	17	71
F5	Coleoptera	Elmidae	Cleptelmis sp.	0	0	0	2	0	0	2
F5	Diptera	Ceratopogonidae	Bezzia sp.	2	0	0	0	1	1	4
F5	Diptera	Chironomidae	Chironomidae spp.	0	1	2	0	0	0	3
F5	Ephemeroptera	Caenidae	Caenis sp.1	0	1	0	0	0	0	1
F5	Oligochaeta	Oligochaeta	Oligochaeta	0	0	0	0	0	1	1
A6	Coleoptera	Elmidae	Cleptelmis sp.	0	0	0	0	1	0	1
A6	Diptera	Chironomidae	Chironomidae spp.	0	0	0	0	1	1	2
A6	Diptera	Tipulidae	Limnophila sp.	8	1	2	1	3	0	15
B6	Diptera	Chironomidae	Chironomidae spp.	2	0	0	0	1	0	3
B6	Megaloptera	Sialidae	Sialis sp.	0	0	0	0	0	1	1
B6	Oligochaeta	Oligochaeta	Oligochaeta	0	1	0	0	0	0	1
B6	Trichoptera	Polycentropodidae	Phylocentropus sp.	0	2	2	1	0	0	5
C6	Coleoptera	Elmidae	Cleptelmis sp.	0	0	0	0	1	0	1
C6	Coleoptera	Curculionidae	Stenopelmus sp.	0	0	0	1	0	0	1
C6	Decapoda	Palaemonidae	Macrobrachium lanchesteri	1	0	0	0	0	0	1
C6	Diptera	Athericidae	Atrichops sp.	0	0	1	0	0	0	1
C6	Diptera	Ceratopogonidae	Bezzia sp.	1	0	0	1	2	0	4
C6	Diptera	Chironomidae	Chironomidae spp.	1	1	1	1	3	1	8
C6	Diptera	Tipulidae	Limnophila sp.	0	0	0	0	1	0	1
C6	Ephemeroptera	Caenidae	Caenis sp.1	0	0	3	0	0	0	3
C6	Ephemeroptera	Ephemeridae	Ephemera sp.	0	1	0	4	4	2	11
C6	Hemiptera	Corixidae	Hesperocorixa sp.	0	0	1	0	0	0	1
C6	Megaloptera	Sialidae	Sialis sp.	0	2	0	0	0	0	2
C6	Oligochaeta	Oligochaeta	Oligochaeta	1	0	0	0	0	0	1
C6	Trichoptera	Calamoceratidae	Anisocentropus sp.	0	0	1	0	0	0	1
C6	Trichoptera	Odontoceridae	Marilia sp.	0	0	0	0	1	0	1
C6	Trichoptera	Polycentropodidae	Pseudoneureclipsis sp.	0	1	0	0	0	0	1
D6	Coleoptera	Elmidae	Cleptelmis sp.	0	0	1	0	0	0	1
D6	Coleoptera	Psephenidae	Eubrianax sp.	3	0	0	0	1	1	5
D6	Coleoptera	Hydrophilidae	Laccobius sp.	0	0	0	0	0	1	1
D6	Diptera	Tipulidae	Antocha sp.	0	0	1	0	0	0	1
D6	Diptera	Rhagionidae	Atherix sp.	1	0	0	0	1	0	2
D6	Diptera	Chironomidae	Chironomidae spp.	2	2	3	2	0	1	10
D6	Diptera	Simulium sp.	Simulium sp.	0	0	1	0	0	0	1
D6	Ephemeroptera	Baetidae	Baetis sp.1	0	1	10	2	0	43	56
D6	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	0	0	0	0	3	0	3
D6	Ephemeroptera	Ephemeridae	Ephemera sp.	8	0	0	0	9	1	18
D6	Ephemeroptera	Heptageniidae	Heptagenia sp.	0	0	0	0	0	3	3
D6	Ephemeroptera	Leptophlebiidae	Thraulodes sp.	2	0	0	0	0	0	2
D6	Hemiptera	Corixidae	Morphocorixa sp.	1	2	0	0	0	1	4
D6	Trichoptera	Hydropsychidae	Ceratopsyche sp.	0	0	5	0	0	3	8
D6	Trichoptera	Philopotamidae	Chimarra sp.	0	0	3	0	0	0	3

Appendix 2.3 (cont.)

Site Code	Order	Family	Species	Replicate no.						Total
				1	2	3	4	5	6	
D6	Trichoptera	Ecnomidae	Ecnomus sp.	2	0	0	0	0	0	2
D6	Trichoptera	Hydroptilidae	Hydroptila sp.	0	2	0	0	0	0	2
E6	Coleoptera	Elmidae	Cleptelmis sp.	0	1	0	0	0	0	1
E6	Diptera	Ceratopogonidae	Bezzia sp.	0	0	0	1	1	0	2
E6	Diptera	Chironomidae	Chironomidae spp.	3	9	10	16	15	13	66
E6	Ephemeroptera	Caenidae	Caenis sp.1	0	0	0	0	1	0	1
E6	Ephemeroptera	Ephemeridae	Litobrancha sp.	0	0	0	0	0	2	2
E6	Oligochaeta	Oligochaeta	Oligochaeta	1	0	0	0	0	1	2
E6	Veneroida	Corbiculidae	Corbicula blandina	0	1	0	0	0	0	1
F6	Coleoptera	Elmidae	Cleptelmis sp.	0	1	0	0	0	0	1
F6	Coleoptera	Curculionidae	Stenopelmus sp.	0	0	1	0	0	0	1
F6	Diptera	Ceratopogonidae	Bezzia sp.	0	1	0	0	0	0	1
F6	Diptera	Chironomidae	Chironomidae spp.	0	2	4	1	1	1	9
F6	Odonata	Gomphidae	Shogomphus sp.	1	0	0	0	0	0	1
F6	Oligochaeta	Oligochaeta	Oligochaeta	0	0	0	1	0	0	1

Appendix 2.4 Average water physicochemical values of the Cheon catchment

(Numbers attached to the site code, 1=Oct, 2=Dec 1995, 3=Feb, 4=Apr, 5=Jun, 6=Aug 1996)
ND=None detectable

Site Code	Water temp (°C)	Velocity (m/sec)	Width (m)	Depth (m)	Discharge (m)	pH	Alkalinity (mg/L)	EC (μS/cm)	TDS (mg/L)	Turbidity (mg/L)
A1	22.7	1.3	5	0.6	3.1	7.7	56	110.9	91.3	25
A2	13.9	0.9	1.9	0.2	0.3	8.1	88	210	144	10.2
A3	14.8	0.4	6	0.2	0.5	7.9	94	179.5	119.6	5.5
A4	24	0.2	5	0.3	0.3	7.6	86	178.4	118.9	6.5
A5	23.5	0.4	5.6	0.1	0.3	8.3	72	141.8	94.4	21
A6	23.2	1.4	5.2	0.3	1.9	7.6	56	124.2	79.5	265
B1	24.6	0.3	7	0.7	1.3	7.2	44	75.3	64.4	26
B2	13.2	0.1	2.3	0.3	ND	8.1	62	141.3	78	21.6
B3	14.1	0	5	0.4	ND	7.4	70	125.5	83.8	5
B4	23	0	4.1	0.3	ND	7.4	46	95.9	63.9	34.7
B5	24	0.3	4.3	0.2	0.3	8.2	36	62.4	41.6	62
B6	23	0.2	3.4	0.3	0.1	8.8	54	106.8	69.4	45
C1	23.9	0.6	7	0.5	1.8	7.8	72	124.3	101.5	83
C2	14.9	0.2	5.2	0.3	0.2	8	144	302	170	7.7
C3	20.3	0	6	0.3	ND	8	190	313.5	208.5	2.1
C4	24.6	0.4	7	0.4	0.8	7.7	74	145.9	97.1	19.8
C5	24.3	0.4	6.7	0.4	0.9	7.3	90	141.6	93.9	41
C6	21.1	0.2	7.8	0.5	0.4	6.2	88	181.9	118.2	90
D1	27.5	0.6	3	0.1	0.2	8.3	116	225	177.6	6.8
D2	19.2	0	0.5	0.1	ND	8.6	120	278	154	1.8
D5	28.2	0.3	3.2	0.1	0.1	7.7	92	187.8	125.2	7.5
D6	26.3	0.2	3.4	0	ND	7.6	112	253.3	162.1	7.3
E1	27.5	0.6	15	3.5	26.8	7.3	90	117	95.9	85
E2	20.8	0.2	15	3.4	0.2	8.3	248	498	278	2.5
E3	21.7	0.1	22	1.7	2.7	8.1	318	541.8	360.5	2.3
E4	27.9	0.1	15	1.1	1.7	7.8	154	308.2	205.2	15.5
E5	28.7	1.3	14.6	0.6	12	8.1	106	224.3	150	125
E6	25.9	0.3	26	1.4	7.9	6.3	132	298.2	193.8	14
F1	25.6	0.4	27	2	17.9	8.2	76	158.2	127.1	65

Appendix 2.4 (cont.)

Site Code	Water temp (°C)	Velocity (m/sec)	Width (m)	Depth (m)	Discharge (m)	pH	Alkalinity (mg/L)	EC (µS/cm)	TDS (mg/L)	Turbidity (mg/L)
F2	21	0.2	24	2	10	8.5	82	501	112	12.8
F3	21	0.1	25	2	3.4	8.2	70	122.7	81.8	7.1
F4	26.2	0.2	20	1.4	3.8	8.1	86	167.3	111.5	12
F5	28.1	0.4	19	2.2	16.6	8.1	92	181.2	120.8	80
F6	25.1	0.2	18	1.5	4.7	7.2	104	223.8	143.2	7.5

Appendix 2.4 (cont.)

Site code	SS (mg/L)	PO4 (mg/L)	NO3 (mg/L)	DO (mg/L)	BOD (mg/L)	Cl (mg/L)	SO4 (mg/L)
A1	154.5	0.14	0.2	6.9	0.9	7.5	9.1
A2	4	0.02	0.03	8.3	2.3	6.5	10.6
A3	4	0.04	0.14	7.6	0.5	6.8	6.7
A4	3	0.6	0.05	5.3	0.7	5.8	10.5
A5	9	0	0.1	6.9	0.7	4.8	13.8
A6	329	0.02	0.1	6.8	1	6.3	14.6
B1	134.5	0.04	0.1	6.4	1.1	4.9	6.6
B2	5.8	0.02	0.02	8.2	1.7	5.9	6.2
B3	3.2	0.02	0.13	1.9	1.1	8.1	4.2
B4	46	1.1	0.08	2	2.4	6.5	20.4
B5	31.5	0	0.1	6.5	1.2	4.6	22.1
B6	23	0.02	0.1	6.4	0.8	5.5	19.8
C1	274.5	0	0	6.6	1.5	7.4	9.3
C2	5.2	0.04	0.02	7.8	1.8	6.7	3.9
C3	2.3	0.1	0.54	7.7	4.3	7	0.5
C4	51.5	0.3	0.25	5.2	1.9	4.5	13.1
C5	17	0.04	0.2	6.8	1	6.1	15.8
C6	105.5	0.02	0.2	6.4	1.6	5.1	14.8
D1	68	0.02	0.3	7.2	1.2	8.5	6.5
D2	1.8	0.04	0.03	7.9	1.3	15.9	3.8
D5	3.5	0.02	0.3	7.3	0.6	9.2	6.9
D6	41	0	0.2	6.6	1.2	10.8	8.1
E1	221	0.07	0	4.1	1.2	4.6	7.1
E2	2	0	0.01	7.8	1.5	7.9	11
E3	2.4	0.07	0.24	9.9	1.3	7.7	9.3
E4	68.5	0.4	0.5	5.5	1.6	4.8	18.5
E5	253	0	0.1	6.9	1.3	3.5	17.1
E6	24	0.04	0.1	6.2	1.4	7.1	11.5
F1	175	0.02	0.1	4.4	1.9	6.2	9.4

Appendix 2.4 (cont.)

Site code	**SS** (mg/L)	**PO4** (mg/L)	**NO3** (mg/L)	**DO** (mg/L)	**BOD** (mg/L)	**Cl** (mg/L)	**SO4** (mg/L)
F2	11.6	0.02	0.03	6.9	1.9	6.2	5.2
F3	4.4	0.07	0.24	9.3	1.1	4.5	3.8
F4	31	0.4	0.3	6.9	1.3	4.2	8.7
F5	93	0	0.2	7.4	0.8	4.6	13.2
F6	9	0.1	0.1	6.8	1.2	5.7	8.3

Appendix 3.1 Benthic macroinvertebrate species list groupings according to subcatchment zones

Order	Catchment zone		
	Upper	Middle	Lower
Coleoptera	Agabus sp. Ancyronyx sp. Berosus sp. Chaenis sp. Cleptelmis sp. Dineutus sp. Dubiraphia sp. Dytiscus sp. Eretes sp. Eubrianax sp. Hexacylloepus sp. Laccophilus sp. Macronychus sp. Neocylloepus sp. Neonelmis sp. Ordobrevia sp. Pelonomus sp. Peltodytes sp. Stenelmis sp. Stenopelmis sp.	Berosus sp. Cleptelmis sp. Dineutus sp. Donacia sp. Eretes sp. Hydrophilus sp. Laccophilus sp. Stenelmis sp. Stenopelmis sp. Tanysphyrus sp.	Cleptelmis sp. Dineutus sp. Hexacylloepus sp. Hydaticus sp. Neocylloepus sp. Stenelmis sp. Stenopelmis sp.
Decapoda	Macrobrachium lanchestri	Macrobrachium lanchestri	Macrobrachium lanchestri
Diptera	Atherix sp. Atrichops sp. Bezzia sp. Chaoborus sp. Chironomidae spp. Culicoides sp. Hexatoma sp. Limnophila sp. Mimomyia sp. Pedicia sp. Simulium sp.	Bezzia sp. Chaoborus sp. Chironomidae spp. Culicoides sp. Hexatoma sp. Limnophila sp.	Bezzia sp. Chaoborus sp. Chironomidae spp. Limnophila sp.
Ephemeroptera	Ameletus sp. Arthroplea sp. Baetis sp1 Baetis sp2 Caenis sp1 Caenis sp2 Campsurus sp. Centroptilum sp. Choroterpes sp. Ephemera sp. Habrophlebiodes sp. Heptagenia sp. Leptophlebia sp. Litobrancha sp.	Baetis sp1 Baetis sp2 Caenis sp1 Caenis sp2 Campsurus sp. Centroptilum sp. Ephoron sp. Heptagenia sp. Litobrancha sp. Potamanthus sp.	Baetis sp1 Caenis sp1 Caenis sp2 Campsurus sp. Centroptilum sp. Ephemera sp. Ephoron sp. Litobrancha sp. Potamanthus sp.

Appendix 3.1 (cont.)

Order	Catchment zone		
	Upper	Middle	Lower
Ephemeroptera	Paraleptophlebia sp.		
	Traverella sp.		
Hemiptera	Belostoma sp.	Abedus sp.	Pentacola sp.
	Hebrus sp.	Cylindrostethus sp.	
	Limnogonus sp.	Mesovelia sp1	
	Mesovelia sp.	Micronecta sp.	
	Mesovelia sp2	Pelocoris sp.	
	Nepa sp.	Rheumatogonus sp.	
	Notonecta sp.	Sphaerodema sp.	
	Palmacorixa sp.	Tenagobia sp.	
	Ranatra sp.		
	Rheumatogonus sp.		
	Rhyacobates sp.		
	Sphaerodema sp.		
	Tenagobia sp.		
	Trepobates sp.		
Lepidoptera	-	Parapoynx sp.	
Megaloptera	Sialis sp.	-	
Mesogastropoda	Anulotaia sp.	Mekongia sp.	Lymnaea sp.
	Filopaludina martensi	Melanoides tuberculata	Mekongia sp2
	Mekongia sp.		Melanoides tuberculata
	Mekongia sp2		
	Melanoides tuberculata		
Odonata	Acisoma sp.	Aphylla sp.	Crocothemis sp.
	Aeshna sp.	Cordulegaster sp.	Hagenius sp.
	Aphylla sp.	Diplacodes sp.	Hesperagrion sp.
	Argiocnemis sp.	Epophthalmia sp.	Macromia sp.
	Cordulegaster sp.	Erpetogomphus sp.	Platycnemis sp.
	Diplacodes sp.	Hagenius sp.	Sinogomphus sp.
	Dromogomphus sp.	Labrogomphus sp.	
	Erpetogomphus sp.	Macromia sp.	
	Hagenius sp.	Macrothemis sp.	
	Labrogomphus sp.	Megalestes sp.	
	Libellulidae sp.	Orthemis sp.	
	Macromia sp.	Platycnemis sp.	
	Macrothemis sp.	Prodasineura sp.	
	Orthemis sp.	Pseudagion sp.	
	Platycnemis sp.	Sinogomphus sp.	
	Prodasineura sp.	Stylurus sp.	
	Progomphus sp.		
	Protoneura sp.		
	Sieboldius sp.		
	Sinogomphus sp.		
Oligochaeta	Oligochaeta	Oligochaeta	Oligochaeta
Plecoptera	Hesperoperla sp.	-	
	Neoperla sp.		
	Phanoperla sp.		

Appendix 3.1 (cont.)

Order	Catchment zone		
	Upper	Middle	Lower
Trichoptera	Amphipsyche meridiana Anisocentropus sp. Ceratopsyche sp. Cheumatopsyche malaysiensis Chimarra sp. Cyrnellus sp. Ecnomus sp. Goera sp. Hydropsyche sp. Hydroptila sp. Leptocerus sp. Leptonema sp. Litobrancha sp. Macrostemum similior Neureclipsis sp. Nytiophylax sp. Oligostomis sp. Orthrotrichia sp. Oxyethira sp. Phylocentropus sp. Polycentropus sp. Tinodes sp. Triaenodes sp.	Amphipsyche meridiana Ceraclea sp. Ecnomus sp. Hydroptila sp. Macrostemum similior Phylocentropus sp. Polycentropus sp. Triaenodes sp.	Amphipsyche meridiana Cheumatopsyche malaysiensis Chimarra sp. Ecnomus sp. Hydropsyche sp. Hydroptila sp. Macrostemum similior Phylocentropus sp. Polycentropus sp.
Veneroida	Corbicula brandina	Corbicula brandina	Corbicula brandina
Total	116 species	65 species	42 species

Appendix 3.2 Macroinvertebrate individuals sampled from the Pong catchment (February 1995-August 1996)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P01	Apr-95	Coleoptera	Neonelmis sp.	7	6	0	3	13	0	29
P01	Apr-95	Coleoptera	Stenelmis sp.	1	0	0	0	1	0	2
P01	Apr-95	Diptera	Chironomidae spp.	0	1	0	0	0	0	1
P01	Apr-95	Diptera	Hexatoma sp.	5	3	3	2	4	0	17
P01	Apr-95	Ephemeroptera	Arthroplea sp.	0	0	0	1	0	0	1
P01	Apr-95	Ephemeroptera	Caenis sp1	0	0	0	0	3	0	3
P01	Apr-95	Ephemeroptera	Habrophlebiodes sp.	0	0	0	0	1	0	1
P01	Apr-95	Mesogastropoda	Filopaludina martensi	0	0	1	2	0	0	3
P01	Apr-95	Plecoptera	Neoperla sp.	0	0	0	0	1	0	1
P01	Apr-95	Trichoptera	Hydropsyche sp.	0	0	0	0	9	0	9
P01	Apr-95	Trichoptera	Macrostemum similior	0	0	0	0	48	1	49
P01	Apr-95	Trichoptera	Oxyethira sp.	0	0	0	0	2	0	2
P01	Apr-95	Veneroida	Corbicula brandina	0	0	2	0	0	1	3
P01	Apr-96	Coleoptera	Cleptelmis sp.	0	2	0	0	0	0	2
P01	Apr-96	Diptera	Chironomidae spp.	0	0	0	0	2	0	2
P01	Apr-96	Diptera	Limnophila sp.	0	0	0	0	0	1	1
P01	Apr-96	Ephemeroptera	Choroterpes sp.	0	1	0	0	0	0	1
P01	Apr-96	Ephemeroptera	Litobrancha sp.	1	0	0	0	0	0	1
P01	Apr-96	Odonata	Sinogomphus sp.	0	0	0	1	0	0	1
P01	Apr-96	Oligochaeta	Oligochaeta	0	1	0	0	0	0	1
P01	Aug-95	Coleoptera	Stenelmis sp.	0	0	1	0	0	0	1
P01	Aug-95	Decapoda	Macrobrachium lanchestri	0	0	0	0	0	1	1
P01	Aug-95	Diptera	Hexatoma sp.	0	1	0	0	0	0	1
P01	Aug-95	Odonata	Macromia sp.	0	0	0	1	0	0	1
P01	Aug-96	Coleoptera	Cleptelmis sp.	0	0	0	0	0	3	3
P01	Aug-96	Diptera	Chironomidae spp.	0	0	0	0	0	2	2
P01	Aug-96	Diptera	Limnophila sp.	1	4	0	1	2	2	10
P01	Aug-96	Ephemeroptera	Caenis sp1	0	0	1	0	0	0	1
P01	Aug-96	Odonata	Erpetogomphus sp.	1	0	0	0	0	0	1
P01	Aug-96	Veneroida	Corbicula brandina	0	0	0	1	1	0	2
P01	Dec-95	Coleoptera	Eubrianax sp.	1	0	0	0	0	0	1
P01	Dec-95	Coleoptera	Stenelmis sp.	0	0	1	0	0	0	1
P01	Dec-95	Decapoda	Macrobrachium lanchestri	1	0	0	0	0	12	13
P01	Dec-95	Diptera	Chironomidae spp.	6	9	8	15	12	1	51
P01	Dec-95	Diptera	Pedicia sp.	0	0	3	1	0	0	4
P01	Dec-95	Ephemeroptera	Caenis sp1	3	0	0	0	1	0	4
P01	Dec-95	Ephemeroptera	Heptagenia sp.	2	0	0	0	0	0	2
P01	Dec-95	Odonata	Erpetogomphus sp.	1	0	0	1	2	2	6
P01	Dec-95	Odonata	Labrogomphus sp.	0	1	0	0	0	0	1
P01	Dec-95	Plecoptera	Phanoperla sp.	1	0	0	0	0	0	1
P01	Dec-95	Trichoptera	Oligostomis sp.	0	0	1	0	0	0	1
P01	Feb-95	Coleoptera	Dineutus sp.	1	0	0	0	0	0	1
P01	Feb-95	Coleoptera	Dytiscus sp.	0	0	0	0	2	1	3
P01	Feb-95	Coleoptera	Hexacylloepus sp.	1	0	8	0	38	0	47
P01	Feb-95	Coleoptera	Neocylloepus sp.	3	12	6	4	51	52	128
P01	Feb-95	Coleoptera	Peltodytes sp.	1	0	0	0	2	0	3
P01	Feb-95	Coleoptera	Stenelmis sp.	0	0	0	0	7	0	7
P01	Feb-95	Diptera	Bezzia sp.	22	3	0	10	2	7	44
P01	Feb-95	Diptera	Chironomidae spp.	25	21	1	27	14	6	97
P01	Feb-95	Diptera	Hexatoma sp.	12	16	4	1	15	10	58
P01	Feb-95	Ephemeroptera	Arthroplea sp.	0	0	0	0	37	32	69
P01	Feb-95	Ephemeroptera	Baetis sp2	1	0	0	0	0	0	1
P01	Feb-95	Ephemeroptera	Caenis sp1	0	4	4	2	20	2	32
P01	Feb-95	Ephemeroptera	Ephemera sp.	1	0	0	0	1	3	5
P01	Feb-95	Mesogastropoda	Mekongia sp1	7	4	8	34	0	19	72
P01	Feb-95	Odonata	Erpetogomphus sp.	0	3	0	0	3	0	6
P01	Feb-95	Odonata	Macrothemis sp.	0	2	0	0	4	0	6
P01	Feb-95	Odonata	Orthemis sp.	0	1	0	0	1	0	2
P01	Feb-95	Odonata	Progomphus sp.	1	2	1	0	0	0	4

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P01	Feb-95	Plecoptera	Neoperla sp.	0	0	0	0	7	0	7
P01	Feb-95	Trichoptera	Hydroptila sp.	0	4	0	0	0	0	4
P01	Feb-95	Trichoptera	Leptocerus sp.	0	1	0	0	2	9	12
P01	Feb-95	Trichoptera	Leptonema sp.	0	0	12	0	17	0	29
P01	Feb-95	Trichoptera	Macrostemum similior	0	0	1	0	2	0	3
P01	Feb-95	Veneroida	Corbicula brandina	13	1	2	0	0	11	27
P01	Feb-96	Coleoptera	Cleptelmis sp.	1	3	0	0	0	0	4
P01	Feb-96	Diptera	Bezzia sp.	0	0	0	0	2	7	9
P01	Feb-96	Diptera	Chironomidae spp.	3	2	1	13	18	7	50
P01	Feb-96	Diptera	Limnophila sp.	4	8	5	1	1	0	19
P01	Feb-96	Ephemeroptera	Baetis sp2	0	0	0	2	1	4	7
P01	Feb-96	Ephemeroptera	Caenis sp1	0	0	2	5	2	0	9
P01	Feb-96	Ephemeroptera	Ephemera sp.	0	0	0	1	0	0	1
P01	Feb-96	Odonata	Acisoma sp.	0	0	1	0	0	0	1
P01	Feb-96	Odonata	Diplacodes sp.	0	0	0	0	0	1	1
P01	Feb-96	Odonata	Erpetogomphus sp.	3	2	5	16	0	3	29
P01	Feb-96	Trichoptera	Anisocentropus sp.	0	0	1	1	0	0	2
P01	Feb-96	Trichoptera	Cheumatopsyche malaysiensis	3	0	3	0	0	0	6
P01	Feb-96	Trichoptera	Cyrnellus sp.	0	1	1	0	0	0	2
P01	Feb-96	Trichoptera	Tinodes sp.	0	1	0	0	0	0	1
P01	Feb-96	Veneroida	Corbicula brandina	4	1	0	0	0	1	6
P01	Jun-95	Coleoptera	Dubiraphia sp.	0	0	0	1	0	0	1
P01	Jun-95	Coleoptera	Stenelmis sp.	0	0	0	0	1	0	1
P01	Jun-95	Odonata	Dromogomphus sp.	0	0	0	0	1	0	1
P01	Jun-95	Odonata	Erpetogomphus sp.	1	0	0	0	0	0	1
P01	Jun-96	Coleoptera	Stenelmis sp.	0	1	0	0	1	0	2
P01	Jun-96	Diptera	Limnophila sp.	0	1	0	0	0	3	4
P01	Jun-96	Oligochaeta	Oligochaeta	0	0	0	0	0	2	2
P01	Jun-96	Trichoptera	Ceratopsyche sp.	1	0	0	0	1	2	4
P01	Oct-95	Diptera	Bezzia sp.	0	0	1	0	0	0	1
P01	Oct-95	Diptera	Chironomidae spp.	0	1	0	0	0	0	1
P02	Apr-95	Coleoptera	Berosus sp.	0	0	3	0	0	1	4
P02	Apr-95	Coleoptera	Hexacylloepus sp.	2	0	4	0	14	15	35
P02	Apr-95	Coleoptera	Laccophilus sp.	0	0	0	0	9	0	9
P02	Apr-95	Coleoptera	Neocylloepus sp.	0	0	1	1	1	2	5
P02	Apr-95	Coleoptera	Neonelmis sp.	0	1	0	0	0	1	2
P02	Apr-95	Coleoptera	Peltodytes sp.	0	0	1	0	3	1	5
P02	Apr-95	Diptera	Bezzia sp.	1	0	45	0	8	6	60
P02	Apr-95	Diptera	Chironomidae spp.	31	0	0	0	74	65	170
P02	Apr-95	Diptera	Hexatoma sp.	0	0	0	0	0	1	1
P02	Apr-95	Ephemeroptera	Arthroplea sp.	0	0	0	0	5	0	5
P02	Apr-95	Ephemeroptera	Caenis sp1	3	0	8	0	0	9	20
P02	Apr-95	Ephemeroptera	Caenis sp2	0	0	0	0	6	0	6
P02	Apr-95	Hemiptera	Tenagobia sp.	1	0	0	0	0	0	1
P02	Apr-95	Odonata	Progomphus sp.	0	0	0	0	0	1	1
P02	Apr-95	Trichoptera	Oxyethira sp.	0	0	0	0	1	1	2
P02	Apr-95	Veneroida	Corbicula brandina	17	0	25	13	0	0	55
P02	Apr-96	Coleoptera	Cleptelmis sp.	0	10	0	0	0	0	10
P02	Apr-96	Coleoptera	Stenelmis sp.	0	0	0	0	0	1	1
P02	Apr-96	Diptera	Atrichops sp.	0	1	0	0	0	2	3
P02	Apr-96	Diptera	Chironomidae spp.	0	1	7	0	1	2	15
P02	Apr-96	Diptera	Simulium sp.	0	0	1	0	0	0	1
P02	Apr-96	Ephemeroptera	Caenis sp1	0	5	0	0	0	1	6
P02	Apr-96	Ephemeroptera	Choroterpes sp.	0	1	0	0	0	0	1
P02	Apr-96	Odonata	Diplacodes sp.	0	0	0	1	0	0	1
P02	Apr-96	Odonata	Erpetogomphus sp.	0	1	0	1	0	0	2
P02	Apr-96	Odonata	Labrogomphus sp.	0	0	0	0	1	0	1
P02	Apr-96	Oligochaeta	Oligochaeta	49	48	11	5	16	24	153
P02	Apr-96	Veneroida	Corbicula brandina	1	0	0	2	2	1	6
P02	Aug-95	Diptera	Chaoborus sp.	0	0	1	0	0	1	2

Appendix 2.3 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P02	Aug-95	Diptera	Chironomidae spp.	1	2	2	0	1	0	6
P02	Aug-95	Ephemeroptera	Baetis sp1	0	0	0	0	0	1	1
P02	Aug-95	Ephemeroptera	Caenis sp2	1	0	0	0	0	0	1
P02	Aug-95	Odonata	Dromogomphus sp.	1	0	0	0	0	0	1
P02	Aug-95	Odonata	Hagenius sp.	1	0	0	0	0	0	1
P02	Aug-95	Odonata	Platycnemis sp.	0	0	1	0	0	0	1
P02	Aug-95	Oligochaeta	Oligochaeta	0	4	5	27	21	7	64
P02	Aug-96	Coleoptera	Stenelmis sp.	0	0	0	0	1	0	1
P02	Aug-96	Diptera	Atrichops sp.	0	0	0	0	0	1	1
P02	Aug-96	Diptera	Chironomidae spp.	0	0	0	0	1	2	3
P02	Aug-96	Oligochaeta	Oligochaeta	0	1	3	1	1	4	10
P02	Aug-96	Trichoptera	Cheumatopsyche malaysiensis	0	0	0	0	3	0	3
P02	Dec-95	Decapoda	Macrobrachium lanchestri	0	0	0	0	1	0	1
P02	Dec-95	Diptera	Bezzia sp.	0	0	0	0	1	0	1
P02	Dec-95	Diptera	Chironomidae spp.	0	11	19	31	7	15	83
P02	Dec-95	Diptera	Pedicia sp.	0	0	0	0	0	2	2
P02	Dec-95	Diptera	Simulium sp.	0	5	19	21	4	1	50
P02	Dec-95	Ephemeroptera	Baetis sp1	0	2	1	1	2	2	8
P02	Dec-95	Ephemeroptera	Caenis sp1	0	33	233	1	29	4	300
P02	Dec-95	Ephemeroptera	Choroterpes sp.	0	0	1	0	0	0	1
P02	Dec-95	Odonata	Erpetogomphus sp.	0	2	3	0	1	1	7
P02	Dec-95	Odonata	Macromia sp.	0	0	1	0	0	0	1
P02	Dec-95	Odonata	Protoneura sp.	0	1	0	0	0	0	1
P02	Dec-95	Plecoptera	Phanoperla sp.	0	0	0	1	0	0	1
P02	Dec-95	Trichoptera	Cheumatopsyche malaysiensis	500	351	6	532	61	12	1462
P02	Dec-95	Trichoptera	Goera sp.	0	0	2	0	0	0	2
P02	Dec-95	Trichoptera	Macrostemum similior	115	65	3	121	30	5	339
P02	Dec-95	Trichoptera	Orthrotrichia sp.	1	2	1	0	2	1	7
P02	Dec-95	Veneroida	Corbicula brandina	0	0	0	0	105	3	108
P02	Feb-95	Coleoptera	Berosus sp.	0	0	0	1	2	0	3
P02	Feb-95	Coleoptera	Dytiscus sp.	0	1	0	0	1	0	2
P02	Feb-95	Coleoptera	Eubrianax sp.	0	1	0	0	0	0	1
P02	Feb-95	Coleoptera	Hexacylloepus sp.	0	9	12	4	21	7	53
P02	Feb-95	Coleoptera	Peltodytes sp.	1	0	2	1	1	0	5
P02	Feb-95	Diptera	Bezzia sp.	6	4	13	1	13	1	38
P02	Feb-95	Diptera	Chironomidae spp.	0	34	8	53	36	2	133
P02	Feb-95	Ephemeroptera	Arthroplea sp.	1	0	1	0	1	0	3
P02	Feb-95	Ephemeroptera	Baetis sp1	0	0	0	0	1	0	1
P02	Feb-95	Ephemeroptera	Caenis sp1	0	5	1	1	32	7	46
P02	Feb-95	Ephemeroptera	Campsurus sp.	0	1	0	2	6	0	9
P02	Feb-95	Hemiptera	Nepa sp.	0	0	0	1	0	0	1
P02	Feb-95	Hemiptera	Tenagobia sp.	0	0	0	1	0	0	1
P02	Feb-95	Mesogastropoda	Mekongia sp2	0	1	0	0	0	0	1
P02	Feb-95	Odonata	Aeshna sp.	1	0	3	5	0	0	9
P02	Feb-95	Odonata	Cordulegaster sp.	0	2	0	0	1	1	4
P02	Feb-95	Odonata	Dromogomphus sp.	2	0	3	1	0	1	7
P02	Feb-95	Odonata	Macromia sp.	0	1	0	0	0	0	1
P02	Feb-95	Odonata	Macrothemis sp.	0	0	2	1	0	0	3
P02	Feb-95	Trichoptera	Ecnomus sp.	0	0	0	0	1	0	1
P02	Feb-95	Trichoptera	Macrostemum similior	0	0	0	0	0	1	1
P02	Feb-95	Trichoptera	Oxyethira sp.	0	0	0	0	3	0	3
P02	Feb-95	Veneroida	Corbicula brandina	151	339	54	73	901	77	1595
P02	Feb-96	Coleoptera	Berosus sp.	0	0	0	0	1	0	1
P02	Feb-96	Coleoptera	Cleptelmis sp.	0	0	7	11	0	15	33
P02	Feb-96	Coleoptera	Dineutus sp.	0	4	7	7	0	0	18
P02	Feb-96	Coleoptera	Eubrianax sp.	0	0	0	1	0	0	1
P02	Feb-96	Coleoptera	Stenelmis sp.	0	4	0	1	13	0	18
P02	Feb-96	Decapoda	Macrobrachium lanchestri	0	1	0	0	0	0	1
P02	Feb-96	Diptera	Bezzia sp.	0	8	1	0	10	1	20
P02	Feb-96	Diptera	Chironomidae spp.	12	103	39	95	62	47	358
P02	Feb-96	Diptera	Limnophila sp.	0	0	0	0	0	1	1
P02	Feb-96	Ephemeroptera	Baetis sp2	10	5	0	42	5	11	73
P02	Feb-96	Ephemeroptera	Caenis sp1	0	3	0	1	1	0	5
P02	Feb-96	Hemiptera	Rheumatogonus sp.	28	0	0	0	0	0	28

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P02	Feb-96	Hemiptera	Tenagobia sp.	0	4	0	0	0	0	4
P02	Feb-96	Odonata	Argiocnemis sp.	0	1	0	0	0	0	1
P02	Feb-96	Odonata	Diplacodes sp.	0	9	0	0	3	0	12
P02	Feb-96	Odonata	Erpetogomphus sp.	2	0	0	2	0	1	5
P02	Feb-96	Odonata	Prodasineura sp.	0	0	0	0	1	0	1
P02	Feb-96	Odonata	Sieboldius sp.	0	0	0	0	0	1	1
P02	Feb-96	Oligochaeta	Oligochaeta	0	2	34	0	3	7	46
P02	Feb-96	Trichoptera	Cheumatopsyche malaysiensis	0	0	0	4	0	32	36
P02	Feb-96	Trichoptera	Macrostemum similior	0	0	0	2	0	10	12
P02	Feb-96	Trichoptera	Orthrotrichia sp.	0	1	0	11	1	5	18
P02	Feb-96	Veneroida	Corbicula brandina	60	13	34	53	18	8	186
P02	Jun-95	Coleoptera	Berosus sp.	0	0	0	1	1	0	2
P02	Jun-95	Coleoptera	Dytiscus sp.	0	1	1	1	2	1	6
P02	Jun-95	Coleoptera	Hexacylloepus sp.	0	0	0	3	0	0	3
P02	Jun-95	Coleoptera	Neocylloepus sp.	1	1	0	2	0	0	4
P02	Jun-95	Coleoptera	Stenelmis sp.	0	2	0	0	0	0	2
P02	Jun-95	Diptera	Chironomidae spp.	3	0	1	1	1	1	7
P02	Jun-95	Ephemeroptera	Caenis sp1	0	2	1	2	1	0	6
P02	Jun-95	Ephemeroptera	Campsurus sp.	3	12	0	0	0	0	15
P02	Jun-95	Hemiptera	Mesovelia sp1	0	0	0	0	4	2	6
P02	Jun-95	Hemiptera	Trepobates sp.	0	0	0	0	1	1	2
P02	Jun-95	Odonata	Erpetogomphus sp.	0	1	1	0	0	0	2
P02	Jun-95	Plecoptera	Neoperla sp.	0	0	0	0	1	0	1
P02	Jun-95	Trichoptera	Hydropsyche sp.	0	1	0	0	0	0	1
P02	Jun-95	Trichoptera	Macrostemum similior	1	0	0	0	0	0	1
P02	Jun-95	Trichoptera	Polycentropus sp.	0	0	0	0	0	1	1
P02	Jun-96	Coleoptera	Cleptelmis sp.	2	1	0	1	1	2	7
P02	Jun-96	Coleoptera	Stenelmis sp.	0	0	0	0	0	9	9
P02	Jun-96	Diptera	Chironomidae spp.	0	0	5	0	0	2	7
P02	Jun-96	Diptera	Limnophila sp.	2	1	0	0	0	1	4
P02	Jun-96	Ephemeroptera	Caenis sp1	0	0	0	0	2	0	2
P02	Jun-96	Ephemeroptera	Centroptilum sp.	0	0	0	2	0	3	5
P02	Jun-96	Odonata	Erpetogomphus sp.	1	0	0	0	0	0	1
P02	Jun-96	Oligochaeta	Oligochaeta	4	5	0	0	0	0	9
P02	Jun-96	Trichoptera	Ceratopsyche sp.	8	9	0	4	3	0	24
P02	Jun-96	Trichoptera	Cheumatopsyche malaysiensis	0	0	0	0	0	44	44
P02	Jun-96	Veneroida	Corbicula brandina	0	0	0	1	2	0	3
P02	Oct-95	Diptera	Chironomidae spp.	4	0	0	0	0	0	4
P02	Oct-95	Diptera	Hexatoma sp.	0	0	0	0	0	1	1
P02	Oct-95	Ephemeroptera	Caenis sp1	0	0	1	0	0	0	1
P02	Oct-95	Odonata	Aphylla sp.	0	0	0	0	1	1	2
P02	Oct-95	Odonata	Macromia sp.	0	0	2	0	1	1	4
P02	Oct-95	Trichoptera	Cheumatopsyche malaysiensis	0	0	0	1	0	0	1
P02	Oct-95	Trichoptera	Macrostemum similior	0	1	0	0	0	1	2
P03	Apr-95	Coleoptera	Hexacylloepus sp.	12	1	5	4	0	5	27
P03	Apr-95	Diptera	Chironomidae spp.	3	1	1	2	0	0	7
P03	Apr-95	Diptera	Hexatoma sp.	9	13	2	0	0	4	28
P03	Apr-95	Ephemeroptera	Caenis sp1	0	1	0	0	0	0	1
P03	Apr-95	Mesogastropoda	Filopaludina martensi	1	0	0	2	0	11	14
P03	Apr-95	Odonata	Aeshna sp.	0	0	0	0	0	1	1
P03	Apr-95	Odonata	Erpetogomphus sp.	2	0	1	1	1	2	7
P03	Apr-95	Trichoptera	Hydropsyche sp.	1	0	0	0	0	1	2
P03	Apr-95	Trichoptera	Oxyethira sp.	0	0	0	0	1	0	1
P03	Apr-95	Veneroida	Corbicula brandina	2	1	2	1	0	1	7
P03	Apr-96	Coleoptera	Cleptelmis sp.	7	0	4	0	0	2	13
P03	Apr-96	Coleoptera	Stenelmis sp.	0	0	1	1	0	0	2
P03	Apr-96	Diptera	Atrichops sp.	1	0	0	0	0	0	1
P03	Apr-96	Diptera	Bezzia sp.	1	0	1	0	0	0	2
P03	Apr-96	Diptera	Chironomidae spp.	2	1	3	0	0	0	6
P03	Apr-96	Diptera	Limnophila sp.	1	5	7	1	0	1	15
P03	Apr-96	Hemiptera	Ranatra sp.	1	0	0	0	0	0	1
P03	Apr-96	Odonata	Erpetogomphus sp.	1	0	0	0	0	0	1
P03	Apr-96	Trichoptera	Chimarra sp.	0	0	1	0	0	0	1
P03	Apr-96	Veneroida	Corbicula brandina	4	5	8	14	20	5	56

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P03	Aug-95	Diptera	Atherix sp.	0	0	0	1	0	0	1
P03	Aug-95	Diptera	Hexatoma sp.	1	0	0	0	0	0	1
P03	Aug-95	Oligochaeta	Oligochaeta	0	0	1	0	2	0	3
P03	Aug-96	Coleoptera	Cleptelmis sp.	1	0	0	0	0	0	1
P03	Aug-96	Coleoptera	Stenopelmis sp.	0	0	1	0	0	0	1
P03	Aug-96	Diptera	Bezzia sp.	0	0	0	0	1	0	1
P03	Aug-96	Diptera	Limnophila sp.	2	1	3	3	0	0	9
P03	Aug-96	Trichoptera	Cheumatopsyche malaysiensis	0	0	0	1	0	0	1
P03	Aug-96	Veneroida	Corbicula brandina	0	0	1	0	0	0	1
P03	Dec-95	Coleoptera	Eubrianax sp.	0	0	0	0	0	1	1
P03	Dec-95	Decapoda	Macrobrachium lanchestri	0	0	0	0	0	1	1
P03	Dec-95	Diptera	Bezzia sp.	0	0	1	0	0	0	1
P03	Dec-95	Diptera	Chironomidae spp.	0	2	1	0	0	2	5
P03	Dec-95	Diptera	Limnophila sp.	0	5	0	1	0	3	9
P03	Dec-95	Ephemeroptera	Choroterpes sp.	0	0	1	0	0	0	1
P03	Dec-95	Ephemeroptera	Litobrancha sp.	2	1	0	0	0	1	4
P03	Dec-95	Hemiptera	Rhyacobates sp.	1	0	0	0	0	0	1
P03	Dec-95	Trichoptera	Goera sp.	0	1	0	0	0	0	1
P03	Dec-95	Trichoptera	Polycentropus sp.	2	2	1	2	2	3	12
P03	Feb-95	Coleoptera	Dineutus sp.	0	0	0	0	0	1	1
P03	Feb-95	Coleoptera	Hexacylloepus sp.	3	8	8	16	6	35	76
P03	Feb-95	Coleoptera	Peltodytes sp.	0	0	0	0	0	1	1
P03	Feb-95	Diptera	Bezzia sp.	2	0	0	0	1	5	8
P03	Feb-95	Diptera	Chironomidae spp.	11	7	19	18	64	48	167
P03	Feb-95	Diptera	Hexatoma sp.	10	0	0	1	0	27	38
P03	Feb-95	Ephemeroptera	Baetis sp1	0	2	0	1	0	5	8
P03	Feb-95	Ephemeroptera	Caenis sp1	3	4	20	7	1	10	45
P03	Feb-95	Ephemeroptera	Caenis sp2	0	0	0	9	1	31	41
P03	Feb-95	Ephemeroptera	Ephemera sp.	0	0	0	0	0	2	2
P03	Feb-95	Hemiptera	Notonecta sp.	1	0	0	0	0	0	1
P03	Feb-95	Odonata	Dromogomphus sp.	0	2	0	0	0	0	2
P03	Feb-95	Odonata	Libellulidae sp1	0	0	3	0	0	0	3
P03	Feb-95	Odonata	Macrothemis sp.	1	1	5	8	4	13	32
P03	Feb-95	Odonata	Platycnemis sp.	0	1	0	0	0	0	1
P03	Feb-95	Odonata	Progomphus sp.	0	1	6	2	1	0	10
P03	Feb-95	Trichoptera	Oxyethira sp.	0	0	0	1	0	1	2
P03	Feb-95	Veneroida	Corbicula brandina	132	3	98	78	45	96	452
P03	Feb-96	Coleoptera	Cleptelmis sp.	55	0	7	8	27	0	97
P03	Feb-96	Coleoptera	Dytiscus sp.	0	0	0	0	0	1	1
P03	Feb-96	Coleoptera	Eretes sp.	1	0	0	0	0	0	1
P03	Feb-96	Coleoptera	Eubrianax sp.	1	0	0	0	0	0	1
P03	Feb-96	Coleoptera	Stenelmis sp.	0	0	0	0	0	9	9
P03	Feb-96	Decapoda	Macrobrachium lanchestri	0	0	0	1	0	0	1
P03	Feb-96	Diptera	Bezzia sp.	0	7	0	0	0	0	7
P03	Feb-96	Diptera	Chironomidae spp.	1	9	0	19	4	0	33
P03	Feb-96	Diptera	Limnophila sp.	37	0	3	13	34	5	92
P03	Feb-96	Diptera	Mimomyia sp.	0	1	0	0	0	0	1
P03	Feb-96	Ephemeroptera	Caenis sp1	1	0	0	5	0	0	6
P03	Feb-96	Ephemeroptera	Centroptilum sp.	0	0	0	11	0	0	11
P03	Feb-96	Ephemeroptera	Choroterpes sp.	9	0	0	0	0	0	9
P03	Feb-96	Ephemeroptera	Ephemera sp.	0	3	0	2	0	0	5
P03	Feb-96	Odonata	Diplacodes sp.	0	1	0	0	0	0	1
P03	Feb-96	Odonata	Erpetogomphus sp.	7	4	7	1	5	4	28
P03	Feb-96	Odonata	Labrogomphus sp.	0	4	0	0	0	0	4
P03	Feb-96	Odonata	Prodasineura sp.	0	1	0	0	0	0	1
P03	Feb-96	Plecoptera	Phanoperla sp.	1	0	1	0	0	1	3
P03	Feb-96	Trichoptera	Cheumatopsyche malaysiensis	265	0	96	1	64	55	481
P03	Feb-96	Trichoptera	Macrostemum similior	16	0	0	0	3	0	19
P03	Feb-96	Trichoptera	Orthrotrichia sp.	0	0	0	4	0	0	4
P03	Feb-96	Trichoptera	Triaenodes sp.	0	0	1	4	0	0	5
P03	Feb-96	Veneroida	Corbicula brandina	1	0	7	4	6	6	24
P03	Jun-95	Coleoptera	Stenelmis sp.	0	0	0	0	2	0	2
P03	Jun-95	Diptera	Hexatoma sp.	0	0	0	0	2	0	2
P03	Jun-95	Plecoptera	Hesperoperla sp.	0	0	1	0	0	0	1

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P03	Jun-95	Trichoptera	Hydropsyche sp.	0	0	0	1	0	0	1
P03	Jun-95	Veneroida	Corbicula brandina	0	0	1	0	0	0	1
P03	Jun-96	Coleoptera	Cleptelmis sp.	0	1	1	0	1	0	3
P03	Jun-96	Coleoptera	Stenelmis sp.	0	0	0	1	0	0	1
P03	Jun-96	Diptera	Limnophila sp.	0	2	0	7	2	0	11
P03	Jun-96	Ephemeroptera	Caenis sp1	0	0	0	1	0	1	2
P03	Jun-96	Oligochaeta	Oligochaeta	0	0	1	0	0	0	1
P03	Jun-96	Trichoptera	Cheumatopsyche malaysiensis	0	1	1	27	66	1	96
P03	Jun-96	Trichoptera	Triaenodes sp.	0	0	0	0	1	0	1
P03	Oct-95	Decapoda	Macrobrachium lanchestri	0	0	1	0	0	2	3
P03	Oct-95	Diptera	Chironomidae spp.	3	0	0	1	2	1	7
P03	Oct-95	Diptera	Hexatoma sp.	1	1	0	0	1	2	5
P03	Oct-95	Odonata	Erpetogomphus sp.	1	1	3	1	0	1	7
P03	Oct-95	Odonata	Macromia sp.	0	0	0	1	0	0	1
P03	Oct-95	Odonata	Progomphus sp.	0	0	1	0	0	0	1
P03	Oct-95	Trichoptera	Cheumatopsyche malaysiensis	0	2	0	0	5	0	7
P03	Oct-95	Trichoptera	Macrostemum similior	0	0	0	0	2	0	2
P03	Oct-95	Trichoptera	Polycentropus sp.	0	0	0	0	1	0	1
P04	Apr-95	Coleoptera	Berosus sp.	1	0	0	0	0	0	1
P04	Apr-95	Coleoptera	Hexacylloepus sp.	1	2	0	0	0	0	3
P04	Apr-95	Coleoptera	Neocylloepus sp.	0	0	2	0	0	0	2
P04	Apr-95	Decapoda	Macrobrachium lanchestri	1	0	0	0	0	0	1
P04	Apr-95	Diptera	Bezzia sp.	3	0	0	0	0	1	4
P04	Apr-95	Diptera	Chironomidae spp.	5	5	11	1	11	8	41
P04	Apr-95	Ephemeroptera	Baetis sp2	0	0	0	0	4	0	4
P04	Apr-95	Ephemeroptera	Caenis sp1	0	1	0	0	3	1	5
P04	Apr-95	Ephemeroptera	Ephemera sp.	0	1	0	2	0	0	3
P04	Apr-95	Mesogastropoda	Mekongia sp2	0	0	3	0	0	2	5
P04	Apr-95	Trichoptera	Hydropsyche sp.	1	0	0	0	0	0	1
P04	Apr-95	Veneroida	Corbicula brandina	2	0	7	0	0	1	10
P04	Apr-96	Coleoptera	Stenelmis sp.	0	0	0	0	1	0	1
P04	Apr-96	Diptera	Chironomidae spp.	1	0	1	0	0	0	2
P04	Apr-96	Ephemeroptera	Caenis sp1	0	0	5	2	0	2	9
P04	Apr-96	Ephemeroptera	Choroterpes sp.	0	0	15	5	4	4	28
P04	Apr-96	Ephemeroptera	Heptagenia sp.	0	1	1	0	0	2	4
P04	Apr-96	Ephemeroptera	Traverella sp.	0	1	0	0	0	0	1
P04	Apr-96	Hemiptera	Sphaerodema sp.	1	1	1	0	0	0	3
P04	Apr-96	Odonata	Erpetogomphus sp.	0	0	0	0	0	1	1
P04	Apr-96	Trichoptera	Ecnomus sp.	10	1	2	0	2	1	16
P04	Apr-96	Trichoptera	Macrostemum similior	0	1	0	0	0	0	1
P04	Apr-96	Veneroida	Corbicula brandina	0	0	2	0	0	0	2
P04	Aug-95	Diptera	Chironomidae spp.	0	0	0	0	1	0	1
P04	Aug-95	Trichoptera	Macrostemum similior	0	0	0	0	1	0	1
P04	Aug-96	Coleoptera	Cleptelmis sp.	0	0	1	0	0	1	2
P04	Aug-96	Coleoptera	Macronychus sp.	0	4	1	0	0	6	11
P04	Aug-96	Coleoptera	Ordobrevia sp.	0	0	0	0	1	0	1
P04	Aug-96	Coleoptera	Stenelmis sp.	0	2	0	0	0	0	2
P04	Aug-96	Diptera	Atrichops sp.	0	0	0	0	0	1	1
P04	Aug-96	Diptera	Chironomidae spp.	0	0	1	0	2	0	3
P04	Aug-96	Ephemeroptera	Baetis sp1	0	0	1	0	0	0	1
P04	Aug-96	Ephemeroptera	Caenis sp1	0	0	0	0	0	2	2
P04	Aug-96	Ephemeroptera	Choroterpes sp.	0	0	0	0	0	3	3
P04	Aug-96	Ephemeroptera	Leptophlebia sp.	2	5	2	3	3	1	16
P04	Aug-96	Oligochaeta	Oligochaeta	0	0	0	1	0	0	1
P04	Aug-96	Plecoptera	Neoperla sp.	0	0	0	0	1	0	1
P04	Aug-96	Trichoptera	Cheumatopsyche malaysiensis	6	4	0	0	12	1	23
P04	Aug-96	Trichoptera	Ecnomus sp.	0	0	0	1	0	0	1
P04	Aug-96	Veneroida	Corbicula brandina	0	1	0	0	0	0	1
P04	Dec-95	Coleoptera	Eubrianax sp.	1	0	0	0	0	0	1
P04	Dec-95	Coleoptera	Stenelmis sp.	1	0	8	1	2	1	13
P04	Dec-95	Decapoda	Macrobrachium lanchestri	0	0	0	1	1	2	4
P04	Dec-95	Diptera	Chironomidae spp.	0	3	4	3	0	0	10
P04	Dec-95	Diptera	Limnophila sp.	0	0	3	0	1	0	4
P04	Dec-95	Ephemeroptera	Caenis sp1	0	6	4	3	4	4	21

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P04	Dec-95	Ephemeroptera	Choroterpes sp.	4	5	5	7	1	2	24
P04	Dec-95	Ephemeroptera	Heptagenia sp.	5	3	0	1	0	4	13
P04	Dec-95	Odonata	Macromia sp.	0	0	0	1	0	0	1
P04	Dec-95	Plecoptera	Phanoperla sp.	1	2	0	1	0	3	7
P04	Dec-95	Trichoptera	Macrostemum similior	0	0	1	0	0	0	1
P04	Dec-95	Trichoptera	Orthrotrichia sp.	1	3	1	0	1	0	6
P04	Dec-95	Veneroida	Corbicula brandina	3	0	0	1	1	3	8
P04	Feb-95	Decapoda	Macrobrachium lanchestri	15	3	28	6	29	14	95
P04	Feb-95	Diptera	Chironomidae spp.	5	17	2	9	0	1	34
P04	Feb-95	Diptera	Culicoides sp.	3	0	8	1	2	0	14
P04	Feb-95	Ephemeroptera	Baetis sp1	0	10	0	2	0	2	14
P04	Feb-95	Ephemeroptera	Caenis sp2	1	0	0	0	0	0	1
P04	Feb-95	Hemiptera	Tenagobia sp.	1	0	3	1	0	0	5
P04	Feb-95	Odonata	Macrothemis sp.	1	0	0	0	0	0	1
P04	Feb-95	Odonata	Platycnemis sp.	0	0	1	0	0	0	1
P04	Feb-96	Decapoda	Macrobrachium lanchestri	0	0	3	0	0	3	6
P04	Feb-96	Diptera	Bezzia sp.	1	1	0	0	0	0	2
P04	Feb-96	Diptera	Chironomidae spp.	158	26	16	13	0	26	239
P04	Feb-96	Diptera	Limnophila sp.	1	0	0	0	0	0	1
P04	Feb-96	Ephemeroptera	Baetis sp1	0	1	0	0	2	1	4
P04	Feb-96	Ephemeroptera	Caenis sp1	15	33	0	4	1	2	55
P04	Feb-96	Ephemeroptera	Choroterpes sp.	1	0	17	0	7	21	46
P04	Feb-96	Ephemeroptera	Heptagenia sp.	0	0	0	0	0	1	1
P04	Feb-96	Hemiptera	Limnogonus sp.	0	0	0	2	0	0	2
P04	Feb-96	Hemiptera	Palmacorixa sp.	5	0	0	0	0	0	5
P04	Feb-96	Odonata	Diplacodes sp.	0	1	1	0	0	0	2
P04	Feb-96	Oligochaeta	Oligochaeta	2	0	0	0	0	0	2
P04	Feb-96	Trichoptera	Ecnomus sp.	0	2	3	1	2	1	9
P04	Feb-96	Veneroida	Corbicula brandina	0	3	0	0	0	1	4
P04	Jun-95	Coleoptera	Chaenis sp.	0	0	0	0	1	0	1
P04	Jun-95	Coleoptera	Pelonomus sp.	0	0	2	0	1	0	3
P04	Jun-95	Decapoda	Macrobrachium lanchestri	0	1	0	0	0	0	1
P04	Jun-95	Diptera	Bezzia sp.	0	0	0	1	0	0	1
P04	Jun-95	Diptera	Chironomidae spp.	3	0	0	3	0	1	7
P04	Jun-95	Hemiptera	Mesovelia sp1	0	0	0	0	0	1	1
P04	Jun-95	Hemiptera	Mesovelia sp2	2	0	0	0	0	0	2
P04	Jun-95	Mesogastropoda	Filopaludina martensi	0	0	0	0	0	1	1
P04	Jun-96	Coleoptera	Cleptelmis sp.	1	2	0	1	0	0	4
P04	Jun-96	Coleoptera	Eubrianax sp.	0	2	0	0	0	0	2
P04	Jun-96	Coleoptera	Stenelmis sp.	0	0	2	2	2	2	8
P04	Jun-96	Coleoptera	Stenopelmis sp.	0	0	0	0	1	0	1
P04	Jun-96	Diptera	Limnophila sp.	1	0	0	0	0	0	1
P04	Jun-96	Ephemeroptera	Choroterpes sp.	0	0	0	0	0	1	1
P04	Jun-96	Ephemeroptera	Paraleptophlebia sp.	0	1	0	0	0	0	1
P04	Jun-96	Ephemeroptera	Traverella sp.	1	5	4	2	0	0	12
P04	Jun-96	Trichoptera	Amphipsyche meridiana	0	0	0	0	1	0	1
P04	Jun-96	Trichoptera	Cheumatopsyche malaysiensis	11	19	8	1	6	4	49
P04	Jun-96	Veneroida	Corbicula brandina	2	0	0	0	0	0	2
P04	Oct-95	Coleoptera	Stenelmis sp.	1	0	0	0	0	0	1
P04	Oct-95	Decapoda	Macrobrachium lanchestri	0	1	0	6	0	1	8
P04	Oct-95	Diptera	Chironomidae spp.	1	0	1	0	0	0	2
P04	Oct-95	Diptera	Hexatoma sp.	0	0	0	1	0	0	1
P04	Oct-95	Diptera	Simulium sp.	0	0	0	1	0	0	1
P04	Oct-95	Ephemeroptera	Ameletus sp.	0	0	0	0	1	0	1
P04	Oct-95	Ephemeroptera	Choroterpes sp.	1	0	0	1	0	0	2
P04	Oct-95	Plecoptera	Neoperla sp.	0	0	0	0	1	0	1
P04	Oct-95	Trichoptera	Ceratopsyche sp.	0	0	0	0	1	0	1
P04	Oct-95	Trichoptera	Leptonema sp.	0	1	0	1	0	1	3
P05	Apr-95	Diptera	Chaoborus sp.	20	29	122	258	12	0	441
P05	Apr-96	Coleoptera	Cleptelmis sp.	0	1	0	0	0	0	1
P05	Apr-96	Diptera	Chaoborus sp.	1	0	0	2	1	1	5
P05	Apr-96	Diptera	Chironomidae spp.	0	5	3	1	1	2	12
P05	Apr-96	Ephemeroptera	Caenis sp2	0	1	0	0	0	0	1

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P05	Aug-95	Diptera	Chaoborus sp.	0	0	0	0	1	0	1
P05	Aug-95	Diptera	Chironomidae spp.	4	2	4	1	1	0	12
P05	Aug-96	Ephemeroptera	Litobrancha sp.	0	0	0	0	0	1	1
P05	Aug-96	Oligochaeta	Oligochaeta	0	0	0	0	0	1	1
P05	Dec-95	Coleoptera	Stenelmis sp.	0	0	2	0	0	0	2
P05	Dec-95	Diptera	Bezzia sp.	0	0	1	0	0	0	1
P05	Dec-95	Diptera	Chaoborus sp.	3	3	4	0	1	5	16
P05	Dec-95	Diptera	Chironomidae spp.	3	0	3	0	2	0	8
P05	Dec-95	Ephemeroptera	Caenis sp1	0	0	0	2	0	0	2
P05	Dec-95	Ephemeroptera	Litobrancha sp.	0	0	0	5	0	0	5
P05	Dec-95	Odonata	Erpetogomphus sp.	0	0	0	0	1	0	1
P05	Dec-95	Oligochaeta	Oligochaeta	0	0	3	0	0	0	3
P05	Feb-95	Diptera	Chaoborus sp.	4	30	0	12	11	6	63
P05	Feb-95	Diptera	Chironomidae spp.	0	0	0	0	3	0	3
P05	Feb-96	Diptera	Chaoborus sp.	24	121	17	19	0	18	199
P05	Feb-96	Diptera	Chironomidae spp.	1	0	2	1	7	0	11
P05	Feb-96	Ephemeroptera	Litobrancha sp.	0	0	0	0	0	1	1
P05	Feb-96	Oligochaeta	Oligochaeta	3	0	0	0	0	0	3
P05	Feb-96	Veneroida	Corbicula brandina	0	0	0	1	0	0	1
P05	Jun-95	Coleoptera	Hexacylloepus sp.	0	3	1	0	0	0	4
P05	Jun-95	Diptera	Bezzia sp.	0	0	0	0	1	0	1
P05	Jun-95	Diptera	Chironomidae spp.	12	7	0	1	16	8	44
P05	Jun-95	Diptera	Hexatoma sp.	0	0	3	0	0	0	3
P05	Jun-95	Ephemeroptera	Caenis sp1	0	1	0	0	0	0	1
P05	Jun-95	Ephemeroptera	Litobrancha sp.	1	1	0	0	1	1	4
P05	Jun-96	Coleoptera	Cleptelmis sp.	0	1	0	2	1	0	4
P05	Jun-96	Diptera	Chironomidae spp.	10	3	4	0	2	5	24
P05	Jun-96	Ephemeroptera	Caenis sp2	0	5	0	0	0	0	5
P05	Jun-96	Ephemeroptera	Litobrancha sp.	3	38	22	24	11	8	106
P05	Jun-96	Oligochaeta	Oligochaeta	2	0	0	0	0	0	2
P05	Jun-96	Trichoptera	Ecnomus sp.	1	0	0	0	0	0	1
P05	Jun-96	Trichoptera	Phylocentropus sp.	5	0	1	1	0	0	7
P05	Oct-95	Coleoptera	Hexacylloepus sp.	0	1	0	0	0	0	1
P05	Oct-95	Diptera	Chironomidae spp.	0	0	0	0	0	1	1
P05	Oct-95	Odonata	Erpetogomphus sp.	1	0	0	0	0	0	1
P06	Apr-95	Coleoptera	Agabus sp.	0	2	0	0	0	0	2
P06	Apr-95	Coleoptera	Ancyronyx sp.	0	1	0	0	0	0	1
P06	Apr-95	Coleoptera	Dineutus sp.	0	1	0	0	0	0	1
P06	Apr-95	Coleoptera	Eubrianax sp.	0	2	2	0	1	0	5
P06	Apr-95	Coleoptera	Hexacylloepus sp.	10	78	37	3	3	6	137
P06	Apr-95	Coleoptera	Stenelmis sp.	0	1	0	0	0	0	1
P06	Apr-95	Decapoda	Macrobrachium lanchestri	0	0	3	0	3	0	6
P06	Apr-95	Diptera	Bezzia sp.	0	0	0	0	0	2	2
P06	Apr-95	Diptera	Chaoborus sp.	0	1	0	0	0	0	1
P06	Apr-95	Diptera	Chironomidae spp.	19	21	22	1	1	5	69
P06	Apr-95	Ephemeroptera	Arthroplea sp.	0	1	0	0	0	0	1
P06	Apr-95	Ephemeroptera	Baetis sp1	1	0	0	0	0	0	1
P06	Apr-95	Ephemeroptera	Caenis sp1	1	3	0	0	0	1	5
P06	Apr-95	Ephemeroptera	Habrophlebiodes sp.	2	17	2	0	2	0	23
P06	Apr-95	Ephemeroptera	Heptagenia sp.	0	0	0	0	1	0	1
P06	Apr-95	Trichoptera	Ecnomus sp.	0	1	0	0	0	0	1
P06	Apr-95	Trichoptera	Nytiophylax sp.	1	3	2	2	0	1	9
P06	Apr-95	Veneroida	Corbicula brandina	1	0	0	1	0	0	2
P06	Apr-96	Coleoptera	Cleptelmis sp.	0	0	3	0	0	0	3
P06	Apr-96	Coleoptera	Stenelmis sp.	1	1	4	19	13	5	43
P06	Apr-96	Diptera	Bezzia sp.	0	0	0	1	0	0	1
P06	Apr-96	Diptera	Chironomidae spp.	6	0	4	9	0	2	21
P06	Apr-96	Ephemeroptera	Caenis sp1	2	2	0	1	0	0	5
P06	Apr-96	Ephemeroptera	Choroterpes sp.	0	0	0	0	5	0	5
P06	Apr-96	Ephemeroptera	Litobrancha sp.	0	0	0	1	0	0	1
P06	Apr-96	Oligochaeta	Oligochaeta	0	0	0	1	3	9	13
P06	Apr-96	Trichoptera	Ecnomus sp.	1	0	1	0	0	0	2
P06	Apr-96	Trichoptera	Polycentropus sp.	2	0	0	1	0	0	3
P06	Aug-95	Diptera	Bezzia sp.	0	0	2	0	0	0	2

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P06	Aug-95	Diptera	Chironomidae spp.	0	1	4	3	0	0	8
P06	Aug-95	Ephemeroptera	Caenis sp1	0	0	0	2	0	0	2
P06	Aug-95	Mesogastropoda	Melanoides tuberculata	0	0	0	0	1	0	1
P06	Aug-95	Odonata	Aphylla sp.	1	0	1	4	0	1	7
P06	Aug-96	Coleoptera	Cleptelmis sp.	0	0	1	1	0	3	5
P06	Aug-96	Coleoptera	Stenopelmis sp.	0	0	0	0	1	0	1
P06	Aug-96	Diptera	Chaoborus sp.	0	1	0	0	0	0	1
P06	Aug-96	Diptera	Chironomidae spp.	4	1	0	0	0	1	6
P06	Aug-96	Ephemeroptera	Caenis sp1	1	0	1	1	1	15	19
P06	Aug-96	Ephemeroptera	Litobrancha sp.	1	0	2	7	1	17	28
P06	Aug-96	Odonata	Labrogomphus sp.	0	1	0	0	0	0	1
P06	Aug-96	Oligochaeta	Oligochaeta	0	0	0	1	0	0	1
P06	Aug-96	Trichoptera	Ecnomus sp.	0	0	0	1	0	0	1
P06	Dec-95	Coleoptera	Stenelmis sp.	1	0	0	0	0	0	1
P06	Dec-95	Diptera	Bezzia sp.	1	1	0	2	1	0	5
P06	Dec-95	Diptera	Chironomidae spp.	1	3	2	1	2	0	9
P06	Dec-95	Ephemeroptera	Baetis sp1	0	0	1	0	0	0	1
P06	Dec-95	Trichoptera	Leptocerus sp.	1	0	0	0	0	0	1
P06	Dec-95	Trichoptera	Phylocentropus sp.	1	0	0	0	2	1	4
P06	Feb-95	Coleoptera	Berosus sp.	0	1	0	0	0	0	1
P06	Feb-95	Coleoptera	Dineutus sp.	0	0	1	0	0	0	1
P06	Feb-95	Coleoptera	Neocylloepus sp.	11	14	0	0	0	1	26
P06	Feb-95	Decapoda	Macrobrachium lanchestri	0	0	0	0	1	0	1
P06	Feb-95	Diptera	Bezzia sp.	0	0	0	0	0	1	1
P06	Feb-95	Diptera	Chironomidae spp.	5	11	0	0	2	0	18
P06	Feb-95	Diptera	Hexatoma sp.	0	1	0	0	0	0	1
P06	Feb-95	Ephemeroptera	Baetis sp1	2	0	0	0	0	0	2
P06	Feb-95	Ephemeroptera	Caenis sp1	4	0	0	0	0	1	5
P06	Feb-95	Ephemeroptera	Choroterpes sp.	1	0	0	0	4	1	6
P06	Feb-95	Hemiptera	Belostoma sp.	1	0	0	0	0	0	1
P06	Feb-95	Mesogastropoda	Anulotaia sp.	3	2	21	4	0	0	30
P06	Feb-95	Odonata	Macrothemis sp.	1	1	0	0	0	0	2
P06	Feb-95	Trichoptera	Ecnomus sp.	0	0	0	2	0	0	2
P06	Feb-95	Trichoptera	Macrostemum similior	16	0	0	0	0	1	17
P06	Feb-95	Trichoptera	Oxyethira sp.	4	1	0	0	0	0	5
P06	Feb-95	Veneroida	Corbicula brandina	124	102	28	47	9	5	315
P06	Feb-96	Coleoptera	Eubrianax sp.	2	0	0	0	0	0	2
P06	Feb-96	Coleoptera	Stenelmis sp.	1	0	0	0	0	0	1
P06	Feb-96	Diptera	Chironomidae spp.	2	0	0	0	0	0	2
P06	Feb-96	Ephemeroptera	Caenis sp1	1	0	1	0	0	0	2
P06	Feb-96	Trichoptera	Neureclipsis sp.	1	0	0	0	0	0	1
P06	Feb-96	Trichoptera	Polycentropus sp.	0	0	1	0	1	0	2
P06	Jun-95	Coleoptera	Eubrianax sp.	1	0	0	0	0	7	8
P06	Jun-95	Coleoptera	Neocylloepus sp.	0	0	0	0	0	3	3
P06	Jun-95	Coleoptera	Stenelmis sp.	0	0	0	0	1	4	5
P06	Jun-95	Diptera	Chironomidae spp.	1	2	4	6	5	12	30
P06	Jun-95	Ephemeroptera	Campsurus sp.	0	0	0	1	0	0	1
P06	Jun-95	Hemiptera	Hebrus sp.	0	0	0	0	1	0	1
P06	Jun-95	Odonata	Aphylla sp.	1	0	0	0	0	0	1
P06	Jun-95	Trichoptera	Ecnomus sp.	1	0	0	0	0	0	1
P06	Jun-95	Trichoptera	Polycentropus sp.	0	1	0	1	0	0	2
P06	Jun-96	Coleoptera	Cleptelmis sp.	0	3	1	0	1	0	5
P06	Jun-96	Diptera	Atrichops sp.	0	1	0	0	3	0	4
P06	Jun-96	Diptera	Chironomidae spp.	0	0	0	3	0	0	3
P06	Jun-96	Ephemeroptera	Litobrancha sp.	0	1	0	1	0	0	2
P06	Jun-96	Odonata	Erpetogomphus sp.	0	1	0	0	0	0	1
P06	Jun-96	Oligochaeta	Oligochaeta	0	0	0	0	1	1	2
P06	Jun-96	Trichoptera	Phylocentropus sp.	0	1	0	0	0	0	1
P06	Oct-95	Diptera	Atherix sp.	0	0	0	1	0	0	1
P06	Oct-95	Diptera	Chironomidae spp.	2	6	12	4	2	0	26
P06	Oct-95	Ephemeroptera	Caenis sp1	0	0	1	1	0	0	2
P06	Oct-95	Ephemeroptera	Leptophlebia sp.	0	0	1	1	0	0	2
P06	Oct-95	Mesogastropoda	Filopaludina martensi	0	0	1	0	0	0	1
P06	Oct-95	Odonata	Aphylla sp.	2	0	0	0	1	1	4

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P06	Oct-95	Odonata	Dromogomphus sp.	0	0	1	0	0	0	1
P06	Oct-95	Oligochaeta	Oligochaeta	1	0	0	0	0	0	1
P06	Oct-95	Trichoptera	Macrostemum similior	0	0	1	0	0	0	1
P06	Oct-95	Trichoptera	Polycentropus sp.	2	0	0	0	0	0	2
P07	Aug-96	Coleoptera	Cleptelmis sp.	0	0	1	1	1	0	3
P07	Aug-96	Coleoptera	Ordobrevia sp.	2	0	0	0	0	0	2
P07	Aug-96	Diptera	Bezzia sp.	1	1	1	0	2	0	5
P07	Aug-96	Diptera	Chironomidae spp.	2	3	1	2	1	0	9
P07	Aug-96	Ephemeroptera	Caenis sp1	0	0	1	0	0	0	1
P07	Aug-96	Ephemeroptera	Litobrancha sp.	0	1	4	0	2	10	17
P07	Aug-96	Megaloptera	Sialis sp.	0	4	0	0	0	0	4
P07	Aug-96	Oligochaeta	Oligochaeta	0	0	0	1	0	1	2
P07	Dec-95	Coleoptera	Eubrianax sp.	0	4	0	0	0	0	4
P07	Dec-95	Coleoptera	Stenelmis sp.	0	3	1	0	1	0	5
P07	Dec-95	Diptera	Bezzia sp.	0	0	0	0	7	0	7
P07	Dec-95	Diptera	Chironomidae spp.	2	1	1	6	3	2	15
P07	Dec-95	Ephemeroptera	Choroterpes sp.	0	2	0	0	0	0	2
P07	Dec-95	Ephemeroptera	Litobrancha sp.	0	0	1	1	1		3
P07	Dec-95	Oligochaeta	Oligochaeta	0	0	0	0	1	0	1
P07	Dec-95	Trichoptera	Ecnomus sp.	0	0	0	0	0	1	1
P07	Dec-95	Trichoptera	Phylocentropus sp.	0	3	0	3	0	6	12
P07	Feb-96	Coleoptera	Cleptelmis sp.	0	0	0	1	0	0	1
P07	Feb-96	Coleoptera	Dineutus sp.	0	0	1	0	0	0	1
P07	Feb-96	Coleoptera	Eubrianax sp.	0	0	1	0	2	0	3
P07	Feb-96	Coleoptera	Eubrianax sp.	1	0	0	1	0	0	2
P07	Feb-96	Coleoptera	Stenelmis sp.	6	0	0	0	1	1	8
P07	Feb-96	Decapoda	Macrobrachium lanchestri	3	2	1	0	1	2	9
P07	Feb-96	Diptera	Bezzia sp.	4	7	9	0	6	2	28
P07	Feb-96	Diptera	Chironomidae spp.	10	4	26	0	11	11	62
P07	Feb-96	Ephemeroptera	Caenis sp1	11	3	0	0	1	0	15
P07	Feb-96	Ephemeroptera	Choroterpes sp.	0	0	5	0	3	6	14
P07	Feb-96	Ephemeroptera	Litobrancha sp.	0	0	0	0	0	0	0
P07	Feb-96	Oligochaeta	Oligochaeta	0	0	0	5	0	1	6
P07	Feb-96	Trichoptera	Ecnomus sp.	0	0	1	0	1	13	15
P07	Feb-96	Trichoptera	Polycentropus sp.	1	1	1	0	1	0	4
P07	Jun-96	Coleoptera	Cleptelmis sp.	0	0	0	0	0	1	1
P07	Jun-96	Diptera	Bezzia sp.	1	0	1	1	2	1	6
P07	Jun-96	Diptera	Chironomidae spp.	3	10	4	0	3	6	26
P07	Jun-96	Ephemeroptera	Caenis sp1	0	0	1	0	0	2	3
P07	Jun-96	Ephemeroptera	Litobrancha sp.	4	16	1	0	0	0	21
P07	Jun-96	Oligochaeta	Oligochaeta	1	3	1	0	0	0	5
P07	Jun-96	Trichoptera	Ecnomus sp.	0	0	1	0	3	0	4
P07	Jun-96	Trichoptera	Phylocentropus sp.	0	0	4	0	5	0	9
P07	Oct-95	Coleoptera	Hexacylloepus sp.	0	1	2	1	1	0	5
P07	Oct-95	Diptera	Atherix sp.	0	0	0	1	0	0	1
P07	Oct-95	Diptera	Chironomidae spp.	14	4	1	5	1	2	27
P07	Oct-95	Ephemeroptera	Caenis sp1	30	1	3	0	0	1	35
P07	Oct-95	Ephemeroptera	Litobrancha sp.	4	21	18	3	12	11	69
P07	Oct-95	Odonata	Aphylla sp.	0	0	0	1	0	0	1
P07	Oct-95	Trichoptera	Polycentropus sp.	1	0	0	1	0	2	4
P08	Apr-95	Coleoptera	Hexacylloepus sp.	0	0	0	0	0	6	6
P08	Apr-95	Diptera	Bezzia sp.	0	1	2	0	0	3	6
P08	Apr-95	Diptera	Chaoborus sp.	0	1	1	1	0	3	6
P08	Apr-95	Diptera	Chironomidae spp.	1	0	1	0	1	5	8
P08	Apr-95	Ephemeroptera	Litobrancha sp.	0	0	0	0	0	4	4
P08	Apr-95	Trichoptera	Polycentropus sp.	0	0	0	0	2	0	2
P08	Apr-96	Diptera	Bezzia sp.	0	3	0	0	0	1	4
P08	Apr-96	Diptera	Chaoborus sp.	1	0	2	0	2	0	5
P08	Apr-96	Diptera	Chironomidae spp.	2	3	2	6	1	1	15
P08	Apr-96	Ephemeroptera	Litobrancha sp.	0	0	1	0	0	0	1
P08	Apr-96	Oligochaeta	Oligochaeta	0	1	0	0	0	0	1
P08	Aug-95	Diptera	Chironomidae spp.	0	1	4	0	0	0	5
P08	Aug-95	Ephemeroptera	Litobrancha sp.	0	2	0	0	0	0	2
P08	Aug-95	Odonata	Aphylla sp.	0	0	1	0	0	0	1

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P08	Aug-95	Trichoptera	Ecnomus sp.	0	0	1	0	0	0	1
P08	Aug-96	Coleoptera	Cleptelmis sp.	0	1	0	1	0	0	2
P08	Aug-96	Diptera	Chaoborus sp.	1	0	0	0	0	0	1
P08	Aug-96	Ephemeroptera	Litobrancha sp.	10	14	5	5	9	9	52
P08	Dec-95	Diptera	Bezzia sp.	3	0	0	1	0	0	4
P08	Dec-95	Diptera	Chironomidae spp.	8	0	0	2	0	0	10
P08	Dec-95	Ephemeroptera	Litobrancha sp.	0	0	0	2	0	0	2
P08	Dec-95	Odonata	Macromia sp.	0	0	1	0	0	0	1
P08	Dec-95	Trichoptera	Ecnomus sp.	1	0	0	0	0	0	1
P08	Dec-95	Trichoptera	Polycentropus sp.	2	0	1	0	3	0	6
P08	Feb-95	Coleoptera	Neocylloepus sp.	0	0	0	0	1	0	1
P08	Feb-95	Diptera	Bezzia sp.	0	0	0	0	6	0	6
P08	Feb-95	Diptera	Chaoborus sp.	7	5	2	1	0	0	15
P08	Feb-95	Diptera	Chironomidae spp.	0	1	0	1	1	3	6
P08	Feb-95	Ephemeroptera	Litobrancha sp.	0	0	0	0	11	1	12
P08	Feb-95	Trichoptera	Ecnomus sp.	0	0	0	0	0	1	1
P08	Feb-96	Coleoptera	Eubrianax sp.	1	1	0	1	0	0	3
P08	Feb-96	Diptera	Bezzia sp.	11	7	7	4	0	1	30
P08	Feb-96	Diptera	Chaoborus sp.	0	0	0	0	1	0	1
P08	Feb-96	Diptera	Chironomidae spp.	0	0	1	0	2	12	15
P08	Feb-96	Ephemeroptera	Caenis sp1	0	0	0	0	2	1	3
P08	Feb-96	Oligochaeta	Oligochaeta	0	0	0	0	0	5	5
P08	Feb-96	Trichoptera	Litobrancha sp.	0	0	5	0	12	0	17
P08	Feb-96	Trichoptera	Neureclipsis sp.	0	2	0	3	0	3	8
P08	Jun-95	Coleoptera	Neocylloepus sp.	6	5	0	8	6	1	26
P08	Jun-95	Diptera	Bezzia sp.	3	0	0	1	2	0	6
P08	Jun-95	Diptera	Chironomidae spp.	4	3	0	1	10	3	21
P08	Jun-95	Ephemeroptera	Litobrancha sp.	2	7	11	10	8	5	43
P08	Jun-95	Trichoptera	Oxyethira sp.	0	1	0	0	0	0	1
P08	Jun-95	Trichoptera	Polycentropus sp.	12	0	0	0	0	0	12
P08	Jun-95	Veneroida	Corbicula brandina	0	0	0	0	0	1	1
P08	Jun-96	Diptera	Bezzia sp.	2	0	1	1	1	1	6
P08	Jun-96	Diptera	Chironomidae spp.	19	0	2	1	6	1	29
P08	Jun-96	Ephemeroptera	Caenis sp1	2	13	11	1	18	2	47
P08	Jun-96	Ephemeroptera	Litobrancha sp.	32	0	0	16	0	0	48
P08	Jun-96	Trichoptera	Ecnomus sp.	2	0	0	1	0	0	3
P08	Oct-95	Diptera	Chironomidae spp.	1	0	0	0	1	0	2
P08	Oct-95	Ephemeroptera	Baetis sp1	0	0	1	0	0	0	1
P08	Oct-95	Ephemeroptera	Litobrancha sp.	1	0	0	0	0	0	1
P08	Oct-95	Oligochaeta	Oligochaeta	0	0	0	0	2	0	2
P08	Oct-95	Trichoptera	Cheumatopsyche malaysiensis	0	0	1	0	0	0	1
P09	Apr-95	Diptera	Bezzia sp.	0	0	4	0	1	0	5
P09	Apr-95	Diptera	Chaoborus sp.	0	0	4	0	0	0	4
P09	Apr-95	Diptera	Chironomidae spp.	9	0	27	28	0	7	71
P09	Apr-96	Diptera	Bezzia sp.	1	2	0	0	1	9	13
P09	Apr-96	Diptera	Chironomidae spp.	14	20	89	13	89	23	248
P09	Apr-96	Ephemeroptera	Potamanthus sp.	0	0	2	0	1	0	3
P09	Apr-96	Trichoptera	Phylocentropus sp.	0	3	0	0	0	1	4
P09	Aug-95	Diptera	Bezzia sp.	0	0	1	0	0	0	1
P09	Aug-95	Diptera	Chaoborus sp.	0	4	1	0	0	0	5
P09	Aug-95	Diptera	Chironomidae spp.	72	41	61	103	91	86	454
P09	Aug-95	Ephemeroptera	Campsurus sp.	0	0	1	0	0	14	15
P09	Aug-95	Trichoptera	Ecnomus sp.	0	0	0	0	0	4	4
P09	Aug-95	Trichoptera	Polycentropus sp.	0	0	2	0	1	0	3
P09	Aug-96	Diptera	Bezzia sp.	1	0	0	0	0	1	2
P09	Aug-96	Diptera	Chironomidae spp.	51	54	27	69	148	211	560
P09	Aug-96	Ephemeroptera	Ephoron sp.	0	0	0	2	0	0	2
P09	Aug-96	Odonata	Macrothemis sp.	0	0	0	0	0	1	1
P09	Aug-96	Odonata	Prodosineura sp.	0	0	0	1	2	0	3
P09	Aug-96	Oligochaeta	Oligochaeta	1	0	0	1	0	0	2
P09	Aug-96	Trichoptera	Ecnomus sp.	0	0	0	3	1	1	5
P09	Dec-95	Diptera	Bezzia sp.	0	0	0	0	0	4	4
P09	Dec-95	Diptera	Chironomidae spp.	37	60	50	49	36	56	288

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P09	Dec-95	Ephemeroptera	Campsurus sp.	0	6	2	1	0	0	9
P09	Dec-95	Odonata	Macromia sp.	0	0	0	0	0	1	1
P09	Dec-95	Oligochaeta	Oligochaeta	0	0	0	0	1	0	1
P09	Dec-95	Trichoptera	Ecnomus sp.	0	2	1	0	0	0	3
P09	Dec-95	Trichoptera	Phylocentropus sp.	0	0	0	0	0	1	1
P09	Feb-95	Diptera	Bezzia sp.	0	4	4	1	0	0	9
P09	Feb-95	Diptera	Chironomidae spp.	103	99	54	48	49	21	374
P09	Feb-96	Diptera	Bezzia sp.	0	0	1	1	1	1	4
P09	Feb-96	Diptera	Chironomidae spp.	12	64	73	48	84	29	310
P09	Feb-96	Ephemeroptera	Caenis sp2	0	1	14	0	4	7	26
P09	Feb-96	Ephemeroptera	Potamanthus sp.	0	1	9	0	0	6	16
P09	Feb-96	Odonata	Diplacodes sp.	0	0	0	0	0	2	2
P09	Feb-96	Odonata	Epophthalmia sp.	0	0	0	0	1	0	1
P09	Feb-96	Odonata	Hagenius sp.	0	0	1	0	1	2	4
P09	Feb-96	Oligochaeta	Oligochaeta	0	0	2	0	0	0	2
P09	Feb-96	Trichoptera	Ecnomus sp.	0	1	2	0	1	0	4
P09	Feb-96	Trichoptera	Phylocentropus sp.	0	0	0	5	0	0	5
P09	Jun-95	Diptera	Chaoborus sp.	16	7	28	1	2	1	55
P09	Jun-95	Diptera	Chironomidae spp.	1	0	2	0	7	5	15
P09	Jun-95	Ephemeroptera	Litobrancha sp.	5	0	0	0	8	6	19
P09	Jun-96	Diptera	Bezzia sp.	0	1	0	1	0	0	2
P09	Jun-96	Diptera	Chaoborus sp.	1	1	3	1	0	0	6
P09	Jun-96	Diptera	Chironomidae spp.	7	59	41	374	142	450	1073
P09	Jun-96	Ephemeroptera	Potamanthus sp.	0	0	0	1	0	1	2
P09	Jun-96	Odonata	Macromia sp.	0	0	0	0	0	1	1
P09	Jun-96	Oligochaeta	Oligochaeta	1	4	0	0	3	10	18
P09	Jun-96	Trichoptera	Ecnomus sp.	0	0	0	4	0	3	7
P09	Jun-96	Trichoptera	Phylocentropus sp.	0	0	0	0	1	0	1
P09	Oct-95	Diptera	Chaoborus sp.	1	0	0	0	1	0	2
P09	Oct-95	Diptera	Chironomidae spp.	78	123	178	142	40	104	665
P09	Oct-95	Ephemeroptera	Campsurus sp.	3	8	0	2	0	5	18
P09	Oct-95	Hemiptera	Abedus sp.	0	0	1	0	0	0	1
P09	Oct-95	Hemiptera	Pelocoris sp.	0	0	1	0	0	0	1
P09	Oct-95	Odonata	Cordulegaster sp.	0	0	0	0	0	1	1
P09	Oct-95	Trichoptera	Ecnomus sp.	5	1	0	2	1	1	10
P09	Oct-95	Trichoptera	Macrostemum similior	23	0	0	0	0	0	23
P09	Oct-95	Trichoptera	Polycentropus sp.	4	0	0	0	0	0	4
P10	Apr-95	Diptera	Chaoborus sp.	1	2	1	4	0	0	8
P10	Apr-95	Diptera	Chironomidae spp.	2	1	0	0	4	0	7
P10	Apr-96	Diptera	Bezzia sp.	0	1	0	0	0	0	1
P10	Apr-96	Diptera	Chironomidae spp.	6	7	34	17	6	5	75
P10	Apr-96	Hemiptera	Sphaerodema sp.	0	0	0	0	1	0	1
P10	Apr-96	Oligochaeta	Oligochaeta	1	0	0	0	0	0	1
P10	Apr-96	Trichoptera	Ecnomus sp.	0	0	0	0	1	0	1
P10	Apr-96	Trichoptera	Phylocentropus sp.	3	1	0	0	2	0	6
P10	Aug-95	Diptera	Chaoborus sp.	0	1	10	1	1	6	19
P10	Aug-95	Diptera	Chironomidae spp.	91	4	3	6	4	3	111
P10	Aug-95	Trichoptera	Polycentropus sp.	0	1	0	0	0	1	2
P10	Aug-96	Diptera	Bezzia sp.	1	4	4	4	2	0	15
P10	Aug-96	Diptera	Chironomidae spp.	2	7	29	0	6	4	48
P10	Aug-96	Odonata	Stylurus sp.	0	0	0	1	0	0	1
P10	Aug-96	Trichoptera	Phylocentropus sp.	0	0	0	0	0	2	2
P10	Dec-95	Diptera	Bezzia sp.	1	0	0	0	0	0	1
P10	Dec-95	Diptera	Chaoborus sp.	2	26	1	1	8	12	50
P10	Dec-95	Diptera	Chironomidae spp.	8	5	1	8	10	6	38
P10	Dec-95	Oligochaeta	Oligochaeta	0	3	1	5	0	0	9
P10	Dec-95	Trichoptera	Phylocentropus sp.	3	2	0	1	2	2	10
P10	Feb-95	Diptera	Bezzia sp.	0	1	0	1	0	1	3
P10	Feb-95	Diptera	Chaoborus sp.	10	4	0	5	15	16	50
P10	Feb-95	Diptera	Chironomidae spp.	0	0	0	0	4	4	8
P10	Feb-96	Diptera	Bezzia sp.	1	0	0	2	1	0	4
P10	Feb-96	Diptera	Chaoborus sp.	0	0	0	0	0	1	1
P10	Feb-96	Diptera	Chironomidae spp.	45	22	55	29	9	41	201
P10	Feb-96	Ephemeroptera	Caenis sp2	1	0	0	12	0	0	13

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P10	Feb-96	Ephemeroptera	Potamanthus sp.	3	0	0	10	0	0	13
P10	Feb-96	Oligochaeta	Oligochaeta	0	0	0	1	0	0	1
P10	Feb-96	Trichoptera	Phylocentropus sp.	1	0	0	0	5	2	8
P10	Jun-95	Diptera	Chaoborus sp.	16	7	31	4	3	6	67
P10	Jun-96	Diptera	Bezzia sp.	1	1	1	0	2	1	6
P10	Jun-96	Diptera	Chaoborus sp.	1	0	0	1	0	2	4
P10	Jun-96	Diptera	Chironomidae spp.	6	1	10	33	5	5	60
P10	Jun-96	Oligochaeta	Oligochaeta	1	1	0	4	0	0	6
P10	Jun-96	Trichoptera	Phylocentropus sp.	1	0	0	0	0	0	1
P10	Oct-95	Diptera	Bezzia sp.	0	0	0	0	1	0	1
P10	Oct-95	Diptera	Chaoborus sp.	3	4	3	1	4	2	17
P10	Oct-95	Diptera	Chironomidae spp.	7	4	7	2	3	7	30
P10	Oct-95	Oligochaeta	Oligochaeta	0	0	0	0	1	6	7
P10	Oct-95	Trichoptera	Ecnomus sp.	0	0	0	2	0	0	2
P10	Oct-95	Trichoptera	Macrostemum similior	2	0	0	0	0	0	2
P10	Oct-95	Trichoptera	Polycentropus sp.	4	3	0	0	0	0	7
P11	Apr-95	Diptera	Bezzia sp.	8	0	0	0	0	2	10
P11	Apr-95	Diptera	Chironomidae spp.	100	1	0	0	4	12	117
P11	Apr-95	Ephemeroptera	Baetis sp1	1	0	0	0	0	0	1
P11	Apr-95	Ephemeroptera	Caenis sp1	6	0	0	0	0	0	6
P11	Apr-95	Odonata	Macrothemis sp.	2	0	0	0	0	0	2
P11	Apr-95	Odonata	Platycnemis sp.	1	0	0	1	0	0	2
P11	Apr-95	Trichoptera	Ecnomus sp.	2	1	1	0	0	2	6
P11	Apr-95	Trichoptera	Hydroptila sp.	15	1	0	0	0	0	16
P11	Apr-95	Trichoptera	Macrostemum similior	1	0	0	0	0	0	1
P11	Apr-95	Trichoptera	Polycentropus sp.	2	0	0	0	1	3	6
P11	Apr-96	Diptera	Bezzia sp.	4	0	0	1	0	7	12
P11	Apr-96	Diptera	Chironomidae spp.	15	13	6	3	4	0	41
P11	Apr-96	Ephemeroptera	Baetis sp2	1	0	0	1	0	0	2
P11	Apr-96	Ephemeroptera	Centroptilum sp.	0	0	0	0	1	0	1
P11	Apr-96	Odonata	Diplacodes sp.	1	0	0	0	0	0	1
P11	Apr-96	Odonata	Labrogomphus sp.	0	0	0	1	0	0	1
P11	Apr-96	Oligochaeta	Oligochaeta	10	2	0	0	2	0	14
P11	Apr-96	Trichoptera	Amphipsyche meridiana	0	0	1	0	0	0	1
P11	Apr-96	Trichoptera	Phylocentropus sp.	1	0	0	2	0	0	3
P11	Apr-96	Trichoptera	Triaenodes sp.	0	0	0	1	0	0	1
P11	Apr-96	Veneroida	Corbicula brandina	2	2	0	0	0	0	4
P11	Aug-95	Diptera	Chaoborus sp.	0	1	0	0	0	1	2
P11	Aug-95	Diptera	Chironomidae spp.	13	44	6	29	40	66	198
P11	Aug-95	Ephemeroptera	Caenis sp1	1	2	0	0	0	0	3
P11	Aug-95	Odonata	Hagenius sp.	0	0	0	0	0	1	1
P11	Aug-95	Odonata	Macrothemis sp.	0	0	0	0	0	1	1
P11	Aug-95	Odonata	Pseudagion sp.	0	0	1	0	0	0	1
P11	Aug-95	Trichoptera	Ecnomus sp.	1	0	0	1	0	0	2
P11	Aug-95	Trichoptera	Polycentropus sp.	1	0	0	0	0	0	1
P11	Aug-96	Diptera	Chironomidae spp.	65	45	82	56	68	94	410
P11	Aug-96	Ephemeroptera	Baetis sp1	0	0	0	1	0	0	1
P11	Aug-96	Ephemeroptera	Caenis sp1	1	1	2	0	0	0	4
P11	Aug-96	Trichoptera	Amphipsyche meridiana	6	9	40	1	2	0	58
P11	Aug-96	Trichoptera	Ecnomus sp.	4	0	10	0	0	0	14
P11	Aug-96	Veneroida	Corbicula brandina	0	0	0	0	0	2	2
P11	Dec-95	Diptera	Chaoborus sp.	2	0	4	1	0	1	8
P11	Dec-95	Diptera	Chironomidae spp.	5	34	21	6	17	8	91
P11	Dec-95	Ephemeroptera	Caenis sp1	2	1	0	0	0	8	11
P11	Dec-95	Oligochaeta	Oligochaeta	3	0	0	0	0	0	3
P11	Dec-95	Trichoptera	Ecnomus sp.	1	1	1	0	0	0	3
P11	Dec-95	Veneroida	Corbicula brandina	1	0	0	0	17	2	20
P11	Feb-95	Coleoptera	Berosus sp.	3	1	1	0	0	0	5
P11	Feb-95	Decapoda	Macrobrachium lanchestri	0	0	2	2	0	0	4
P11	Feb-95	Diptera	Chironomidae spp.	2	7	18	14	0	40	81
P11	Feb-95	Diptera	Culicoides sp.	9	2	3	4	0	12	30
P11	Feb-95	Diptera	Hexatoma sp.	0	0	0	0	0	1	1
P11	Feb-95	Ephemeroptera	Caenis sp1	0	2	1	1	0	2	6
P11	Feb-95	Lepidoptera	Parapoynx sp.	0	0	0	0	0	1	1

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P11	Feb-95	Odonata	Cordulegaster sp.	0	0	1	0	0	1	2
P11	Feb-95	Trichoptera	Ecnomus sp.	0	0	0	0	0	6	6
P11	Feb-96	Diptera	Bezzia sp.	0	9	3	1	1	0	14
P11	Feb-96	Diptera	Chironomidae spp.	8	55	26	9	48	24	170
P11	Feb-96	Ephemeroptera	Baetis sp2	0	0	0	0	2	0	2
P11	Feb-96	Ephemeroptera	Caenis sp2	0	1	0	0	2	20	23
P11	Feb-96	Odonata	Diplacodes sp.	0	0	0	0	0	1	1
P11	Feb-96	Odonata	Sinogomphus sp.	0	1	0	0	0	0	1
P11	Feb-96	Oligochaeta	Oligochaeta	0	0	0	1	0	3	4
P11	Feb-96	Trichoptera	Ecnomus sp.	0	1	0	0	0	0	1
P11	Feb-96	Trichoptera	Phylocentropus sp.	0	0	1	0	1	0	2
P11	Feb-96	Veneroida	Corbicula brandina	1	0	0	5	8	0	14
P11	Jun-95	Coleoptera	Berosus sp.	0	0	0	0	1	0	1
P11	Jun-95	Diptera	Bezzia sp.	2	0	0	0	0	0	2
P11	Jun-95	Diptera	Chaoborus sp.	0	0	0	0	0	2	2
P11	Jun-95	Diptera	Chironomidae spp.	26	6	2	19	1	33	87
P11	Jun-95	Ephemeroptera	Caenis sp2	0	0	1	0	0	0	1
P11	Jun-95	Hemiptera	Mesovelia sp1	0	0	0	0	5	0	5
P11	Jun-95	Trichoptera	Ecnomus sp.	1	3	1	3	1	3	12
P11	Jun-95	Trichoptera	Macrostemum similior	0	0	0	1	0	0	1
P11	Jun-95	Trichoptera	Polycentropus sp.	0	0	0	2	0	0	2
P11	Jun-96	Coleoptera	Stenopelmis sp.	1	0	0	0	0	0	1
P11	Jun-96	Diptera	Chironomidae spp.	3	16	7	4	5	34	69
P11	Jun-96	Diptera	Limnophila sp.	1	0	0	0	0	0	1
P11	Jun-96	Oligochaeta	Oligochaeta	3	0	1	0	2	0	6
P11	Jun-96	Trichoptera	Amphipsyche meridiana	5	0	0	3	1	1	10
P11	Jun-96	Trichoptera	Ecnomus sp.	0	1	0	3	0	10	14
P11	Jun-96	Trichoptera	Phylocentropus sp.	0	0	0	1	0	0	1
P11	Oct-95	Coleoptera	Donacia sp.	0	1	0	0	0	0	1
P11	Oct-95	Decapoda	Macrobrachium lanchestri	1	0	0	5	0	0	6
P11	Oct-95	Diptera	Bezzia sp.	0	1	2	0	0	0	3
P11	Oct-95	Diptera	Chironomidae spp.	10	18	13	12	12	5	70
P11	Oct-95	Hemiptera	Abedus sp.	0	0	0	0	0	1	1
P11	Oct-95	Hemiptera	Pelocoris sp.	0	0	0	0	0	2	2
P11	Oct-95	Odonata	Aphylla sp.	0	0	0	0	0	2	2
P11	Oct-95	Odonata	Hagenius sp.	1	0	0	0	0	0	1
P11	Oct-95	Odonata	Orthemis sp.	0	0	1	0	0	1	2
P11	Oct-95	Odonata	Platycnemis sp.	0	0	0	0	0	1	1
P11	Oct-95	Trichoptera	Ecnomus sp.	4	0	0	0	1	0	5
P11	Oct-95	Trichoptera	Macrostemum similior	1	0	0	0	0	1	2
P11	Oct-95	Trichoptera	Polycentropus sp.	1	1	1	0	2	0	5
P12	Apr-95	Coleoptera	Berosus sp.	0	2	0	0	0	1	3
P12	Apr-95	Coleoptera	Laccophilus sp.	0	0	0	0	2	88	90
P12	Apr-95	Decapoda	Macrobrachium lanchestri	0	0	0	0	0	1	1
P12	Apr-95	Diptera	Bezzia sp.	0	0	0	2	0	16	18
P12	Apr-95	Diptera	Chironomidae spp.	25	27	0	70	6	34	162
P12	Apr-95	Ephemeroptera	Caenis sp1	0	1	0	11	0	1	13
P12	Apr-95	Lepidoptera	Parapoynx sp.	0	0	0	2	0	0	2
P12	Apr-95	Mesogastropoda	Mekongia sp1	5	12	0	0	0	0	17
P12	Apr-95	Odonata	Hagenius sp.	0	0	0	1	0	0	1
P12	Apr-95	Odonata	Macrothemis sp.	0	0	0	3	0	0	3
P12	Apr-95	Trichoptera	Ecnomus sp.	0	0	0	1	0	0	1
P12	Apr-95	Trichoptera	Polycentropus sp.	0	1	0	0	0	0	1
P12	Apr-95	Veneroida	Corbicula brandina	11	4	0	11	0	0	26
P12	Apr-96	Coleoptera	Cleptelmis sp.	0	0	0	0	2	0	2
P12	Apr-96	Diptera	Bezzia sp.	0	0	0	0	8	0	8
P12	Apr-96	Diptera	Chironomidae spp.	15	6	6	12	13	10	62
P12	Apr-96	Ephemeroptera	Centroptilum sp.	0	0	0	0	2	0	2
P12	Apr-96	Trichoptera	Phylocentropus sp.	0	0	0	0	1	0	1
P12	Apr-96	Veneroida	Corbicula brandina	0	0	0	0	2	0	2
P12	Aug-95	Diptera	Bezzia sp.	0	0	0	0	0	1	1
P12	Aug-95	Diptera	Chironomidae spp.	1	8	3	1	1	4	18
P12	Aug-95	Oligochaeta	Oligochaeta	0	1	0	0	0	0	1
P12	Aug-96	Coleoptera	Tanysphyrus sp.	0	0	0	0	0	1	1

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P12	Aug-96	Diptera	Chironomidae spp.	1	1	3	2	3	2	12
P12	Aug-96	Trichoptera	Phylocentropus sp.	2	0	0	0	0	0	2
P12	Dec-95	Coleoptera	Stenelmis sp.	0	1	7	0	1	0	9
P12	Dec-95	Diptera	Bezzia sp.	3	1	0	0	1	0	5
P12	Dec-95	Diptera	Chironomidae spp.	9	12	5	2	38	11	77
P12	Dec-95	Ephemeroptera	Baetis sp1	0	2	1	0	0	0	3
P12	Dec-95	Ephemeroptera	Caenis sp1	10	0	3	0	0	0	13
P12	Dec-95	Odonata	Aphylla sp.	0	0	1	0	0	1	2
P12	Dec-95	Odonata	Erpetogomphus sp.	0	0	1	0	0	1	2
P12	Dec-95	Odonata	Macromia sp.	1	0	0	0	0	0	1
P12	Dec-95	Odonata	Megalestes sp.	0	1	0	0	0	1	2
P12	Dec-95	Oligochaeta	Oligochaeta	0	0	2	0	0	0	2
P12	Dec-95	Trichoptera	Ecnomus sp.	1	0	3	0	0	0	4
P12	Dec-95	Veneroida	Corbicula brandina	0	0	4	0	0	0	4
P12	Feb-95	Coleoptera	Dineutus sp.	0	0	0	0	0	1	1
P12	Feb-95	Diptera	Bezzia sp.	1	3	6	1	2	0	13
P12	Feb-95	Diptera	Chironomidae spp.	29	29	5	15	34	88	200
P12	Feb-95	Ephemeroptera	Caenis sp1	1	0	0	0	3	1	5
P12	Feb-95	Hemiptera	Tenagobia sp.	0	0	0	0	0	2	2
P12	Feb-95	Lepidoptera	Parapoynx sp.	0	0	0	0	0	1	1
P12	Feb-95	Mesogastropoda	Melanoides tuberculata	1	0	0	0	0	0	1
P12	Feb-95	Trichoptera	Polycentropus sp.	0	1	0	0	2	0	3
P12	Feb-95	Veneroida	Corbicula brandina	1	1	4	0	0	0	6
P12	Feb-96	Decapoda	Macrobrachium lanchestri	0	1	0	0	0	0	1
P12	Feb-96	Diptera	Bezzia sp.	0	1	0	0	0	0	1
P12	Feb-96	Diptera	Chironomidae spp.	8	20	58	25	11	41	163
P12	Feb-96	Hemiptera	Micronecta sp.	0	1	0	0	0	0	1
P12	Feb-96	Trichoptera	Ecnomus sp.	0	0	0	2	0	0	2
P12	Feb-96	Veneroida	Corbicula brandina	1	0	0	0	0	0	1
P12	Jun-95	Coleoptera	Hydrophilus sp.	0	0	0	1	0	0	1
P12	Jun-95	Coleoptera	Stenopelmis sp.	0	0	0	1	0	0	1
P12	Jun-95	Diptera	Bezzia sp.	0	0	1	0	2	1	4
P12	Jun-95	Diptera	Chironomidae spp.	4	0	29	8	11	0	52
P12	Jun-95	Ephemeroptera	Caenis sp1	0	0	17	4	1	0	22
P12	Jun-95	Ephemeroptera	Caenis sp2	0	0	1	0	0	0	1
P12	Jun-95	Odonata	Hagenius sp.	0	0	1	2	0	0	3
P12	Jun-95	Odonata	Orthemis sp.	0	0	1	0	0	0	1
P12	Jun-95	Odonata	Platycnemis sp.	0	0	1	0	0	0	1
P12	Jun-95	Trichoptera	Ecnomus sp.	0	0	5	1	0	0	6
P12	Jun-95	Trichoptera	Hydroptila sp.	0	0	1	0	0	0	1
P12	Jun-96	Coleoptera	Eretes sp.	0	2	0	0	0	0	2
P12	Jun-96	Diptera	Bezzia sp.	0	0	2	2	0	0	4
P12	Jun-96	Diptera	Chaoborus sp.	0	0	1	0	0	0	1
P12	Jun-96	Diptera	Chironomidae spp.	1	22	47	2	0	2	74
P12	Jun-96	Ephemeroptera	Caenis sp1	0	0	3	0	0	0	3
P12	Jun-96	Ephemeroptera	Heptagenia sp.	0	0	0	0	0	1	1
P12	Jun-96	Ephemeroptera	Litobrancha sp.	0	0	0	1	0	0	1
P12	Jun-96	Hemiptera	Cylindrostethus sp.	0	1	4	3	3	0	11
P12	Jun-96	Hemiptera	Rheumatogonus sp.	0	0	0	0	1	0	1
P12	Jun-96	Odonata	Prodasineura sp.	0	0	0	0	0	2	2
P12	Jun-96	Oligochaeta	Oligochaeta	2	0	2	0	0	0	4
P12	Jun-96	Trichoptera	Ceraclea sp.	0	2	2	0	0	0	4
P12	Jun-96	Trichoptera	Ecnomus sp.	0	1	1	0	0	0	2
P12	Jun-96	Trichoptera	Phylocentropus sp.	0	1	4	1	0	0	6
P12	Oct-95	Decapoda	Macrobrachium lanchestri	0	0	0	1	1	1	3
P12	Oct-95	Diptera	Bezzia sp.	0	0	0	3	0	0	3
P12	Oct-95	Diptera	Chironomidae spp.	11	17	0	1	7	0	36
P12	Oct-95	Odonata	Aphylla sp.	0	0	0	1	0	0	1
P12	Oct-95	Odonata	Hagenius sp.	0	1	0	0	0	0	1
P12	Oct-95	Trichoptera	Polycentropus sp.	5	4	1	3	1	7	21
P13	Apr-95	Diptera	Bezzia sp.	0	2	0	0	0	0	2
P13	Apr-95	Diptera	Chaoborus sp.	3	1	2	6	6	4	22
P13	Apr-95	Diptera	Chironomidae spp.	3	5	0	4	0	2	14
P13	Apr-96	Coleoptera	Stenelmis sp.	0	0	0	0	1	0	1

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P13	Apr-96	Diptera	Bezzia sp.	2	0	1	1	2	0	6
P13	Apr-96	Diptera	Chironomidae spp.	3	0	3	6	1	0	13
P13	Apr-96	Ephemeroptera	Caenis sp2	0	1	0	0	0	0	1
P13	Apr-96	Ephemeroptera	Litobrancha sp.	6	2	0	0	0	2	10
P13	Apr-96	Oligochaeta	Oligochaeta	0	0	1	0	0	0	1
P13	Apr-96	Trichoptera	Ecnomus sp.	0	0	0	0	1	0	1
P13	Apr-96	Trichoptera	Phylocentropus sp.	0	0	0	1	0	0	1
P13	Aug-95	Diptera	Bezzia sp.	0	1	0	0	0	0	1
P13	Aug-95	Diptera	Chironomidae spp.	3	0	1	1	2	4	11
P13	Aug-95	Ephemeroptera	Caenis sp1	1	0	0	0	0	0	1
P13	Aug-95	Ephemeroptera	Litobrancha sp.	0	0	0	0	1	0	1
P13	Aug-96	Coleoptera	Cleptelmis sp.	0	0	1	0	0	0	1
P13	Aug-96	Diptera	Bezzia sp.	1	0	0	0	0	0	1
P13	Aug-96	Diptera	Chironomidae spp.	5	3	1	1	1	1	12
P13	Aug-96	Oligochaeta	Oligochaeta	0	0	0	0	0	1	1
P13	Aug-96	Trichoptera	Phylocentropus sp.	0	2	2	0	0	1	5
P13	Dec-95	Coleoptera	Stenelmis sp.	0	0	0	1	0	0	1
P13	Dec-95	Diptera	Bezzia sp.	2	0	0	0	1	0	3
P13	Dec-95	Diptera	Chaoborus sp.	0	0	1	0	0	0	1
P13	Dec-95	Diptera	Chironomidae spp.	7	0	0	3	10	25	45
P13	Dec-95	Ephemeroptera	Litobrancha sp.	0	1	2	5	0	0	8
P13	Dec-95	Trichoptera	Ecnomus sp.	0	0	0	0	1	0	1
P13	Feb-95	Diptera	Bezzia sp.	1	0	0	0	0	0	1
P13	Feb-95	Diptera	Chaoborus sp.	2	2	1	3	0	3	11
P13	Feb-95	Diptera	Chironomidae spp.	1	1	10	5	3	2	22
P13	Feb-95	Odonata	Macromia sp.	0	1	0	0	0	0	1
P13	Feb-96	Diptera	Bezzia sp.	0	1	0	0	0	2	3
P13	Feb-96	Diptera	Chaoborus sp.	1	0	0	0	0	0	1
P13	Feb-96	Diptera	Chironomidae spp.	3	5	2	5	7	1	23
P13	Feb-96	Ephemeroptera	Caenis sp2	0	0	0	0	1	0	1
P13	Jun-95	Diptera	Chaoborus sp.	0	0	1	0	0	0	1
P13	Jun-95	Diptera	Chironomidae spp.	10	16	23	19	16	9	93
P13	Jun-96	Diptera	Bezzia sp.	2	0	0	0	0	0	2
P13	Jun-96	Diptera	Chironomidae spp.	28	3	0	5	0	3	39
P13	Jun-96	Oligochaeta	Oligochaeta	0	0	0	0	0	1	1
P13	Jun-96	Trichoptera	Phylocentropus sp.	1	2	0	0	1	6	10
P13	Oct-95	Coleoptera	Hexacylloepus sp.	1	0	0	0	0	0	1
P13	Oct-95	Decapoda	Macrobrachium lanchestri	0	0	1	1	1	0	3
P13	Oct-95	Diptera	Chironomidae spp.	6	0	1	1	21	3	32
P13	Oct-95	Ephemeroptera	Caenis sp1	1	0	0	0	0	0	1
P13	Oct-95	Ephemeroptera	Litobrancha sp.	8	4	0	0	0	0	12
P13	Oct-95	Mesogastropoda	Melanoides tuberculata	0	0	0	0	0	1	1
P13	Oct-95	Trichoptera	Ecnomus sp.	2	1	0	0	0	0	3
P13	Oct-95	Trichoptera	Polycentropus sp.	0	4	0	0	0	0	4
P14	Apr-95	Diptera	Bezzia sp.	0	1	0	0	0	1	2
P14	Apr-95	Diptera	Chaoborus sp.	0	1	0	1	0	0	2
P14	Apr-95	Diptera	Chironomidae spp.	0	1	18	15	14	14	62
P14	Apr-95	Mesogastropoda	Mekongia sp2	1	0	0	0	0	4	5
P14	Apr-95	Odonata	Hagenius sp.	0	0	0	0	0	1	1
P14	Apr-95	Veneroida	Corbicula brandina	3	2	0	0	3	1	9
P14	Apr-96	Diptera	Bezzia sp.	0	0	0	1	1	7	9
P14	Apr-96	Diptera	Chironomidae spp.	23	22	19	9	8	78	159
P14	Apr-96	Ephemeroptera	Caenis sp2	0	1	1	0	0	1	3
P14	Apr-96	Odonata	Sinogomphus sp.	1	0	0	0	0	0	1
P14	Apr-96	Oligochaeta	Oligochaeta	8	0	0	2	0	0	10
P14	Apr-96	Trichoptera	Ecnomus sp.	0	0	0	0	0	1	1
P14	Aug-95	Diptera	Chironomidae spp.	5	6	3	1	4	0	19
P14	Aug-95	Oligochaeta	Oligochaeta	0	0	1	1	1	0	3
P14	Aug-95	Trichoptera	Polycentropus sp.	0	1	0	0	0	0	1
P14	Aug-96	Diptera	Bezzia sp.	1	0	0	0	0	0	1
P14	Aug-96	Diptera	Chironomidae spp.	2	0	2	0	3	5	12
P14	Aug-96	Ephemeroptera	Caenis sp1	0	1	1	0	0	0	2
P14	Aug-96	Ephemeroptera	Ephoron sp.	0	0	0	0	1	0	1
P14	Aug-96	Trichoptera	Amphipsyche meridiana	0	2	1	1	1	0	5

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P14	Aug-96	Trichoptera	Cheumatopsyche malaysiensis	0	0	0	0	7	0	7
P14	Aug-96	Trichoptera	Ecnomus sp.	0	1	0	0	0	0	1
P14	Aug-96	Trichoptera	Phylocentropus sp.	1	2	0	0	0	0	3
P14	Dec-95	Diptera	Chironomidae spp.	20	7	9	5	11	2	54
P14	Dec-95	Ephemeroptera	Campsurus sp.	0	1	0	0	0	0	1
P14	Dec-95	Oligochaeta	Oligochaeta	0	0	0	2	5	6	13
P14	Feb-95	Coleoptera	Dineutus sp.	0	0	1	0	0	0	1
P14	Feb-95	Decapoda	Macrobrachium lanchestri	2	0	0	0	0	0	2
P14	Feb-95	Diptera	Bezzia sp.	0	0	0	0	0	1	1
P14	Feb-95	Diptera	Chironomidae spp.	42	24	15	6	7	7	101
P14	Feb-95	Ephemeroptera	Baetis spl	1	0	0	0	0	0	1
P14	Feb-95	Ephemeroptera	Caenis spl	34	40	17	0	2	3	96
P14	Feb-95	Ephemeroptera	Caenis sp2	1	3	0	0	0	0	4
P14	Feb-95	Mesogastropoda	Mekongia sp2	0	3	0	18	9	0	30
P14	Feb-95	Odonata	Crocothemis sp.	1	2	0	0	0	0	3
P14	Feb-95	Odonata	Hesperagrion sp.	2	0	0	0	0	0	2
P14	Feb-95	Odonata	Platycnemis sp.	0	2	0	0	0	0	2
P14	Feb-95	Trichoptera	Hydropsyche sp.	1	2	0	0	0	0	3
P14	Feb-95	Trichoptera	Hydroptila sp.	0	0	1	0	0	0	1
P14	Feb-95	Trichoptera	Polycentropus sp.	5	1	4	0	1	0	11
P14	Feb-96	Diptera	Bezzia sp.	0	0	0	0	1	1	2
P14	Feb-96	Diptera	Chironomidae spp.	39	31	7	7	8	14	106
P14	Feb-96	Ephemeroptera	Caenis sp2	6	12	0	0	0	0	18
P14	Feb-96	Oligochaeta	Oligochaeta	0	1	0	0	0	0	1
P14	Feb-96	Trichoptera	Ecnomus sp.	1	0	0	0	0	0	1
P14	Jun-95	Coleoptera	Hydaticus sp.	0	0	1	0	0	0	1
P14	Jun-95	Diptera	Bezzia sp.	4	0	1	0	6	2	13
P14	Jun-95	Diptera	Chironomidae spp.	29	2	8	0	9	3	51
P14	Jun-95	Ephemeroptera	Campsurus sp.	0	0	0	1	0	0	1
P14	Jun-96	Diptera	Bezzia sp.	0	0	0	0	1	0	1
P14	Jun-96	Diptera	Chironomidae spp.	20	6	0	43	0	0	69
P14	Jun-96	Ephemeroptera	Caenis sp2	2	0	1	0	0	0	3
P14	Jun-96	Ephemeroptera	Potamanthus sp.	2	0	7	0	0	0	9
P14	Jun-96	Oligochaeta	Oligochaeta	2	0	0	0	1	0	3
P14	Oct-95	Diptera	Chironomidae spp.	12	7	5	10	3	8	45
P14	Oct-95	Ephemeroptera	Ephemera sp.	1	0	0	0	0	0	1
P14	Oct-95	Oligochaeta	Oligochaeta	0	3	0	1	3	0	7
P15	Apr-95	Diptera	Chironomidae spp.	3	0	0	0	0	1	4
P15	Apr-95	Veneroida	Corbicula brandina	3	0	0	0	0	0	3
P15	Apr-96	Diptera	Bezzia sp.	0	0	1	0	0	0	1
P15	Apr-96	Diptera	Chironomidae spp.	6	0	1	0	0	0	7
P15	Apr-96	Oligochaeta	Oligochaeta	1	0	1	0	0	1	3
P15	Apr-96	Veneroida	Corbicula brandina	0	0	0	5	0	1	6
P15	Aug-95	Diptera	Bezzia sp.	0	0	0	1	2	0	3
P15	Aug-95	Diptera	Chironomidae spp.	0	0	11	10	6	10	37
P15	Aug-95	Oligochaeta	Oligochaeta	0	1	2	0	0	3	6
P15	Aug-96	Diptera	Bezzia sp.	0	0	0	0	0	0	0
P15	Aug-96	Diptera	Chironomidae spp.	4	1	5	3	5	3	21
P15	Aug-96	Oligochaeta	Oligochaeta	4	2	4	0	4	2	16
P15	Dec-95	Diptera	Chaoborus sp.	0	0	1	0	0	0	1
P15	Dec-95	Diptera	Chironomidae spp.	0	0	2	0	0	0	2
P15	Dec-95	Diptera	Limnophila sp.	1	0	0	0	0	0	1
P15	Dec-95	Oligochaeta	Oligochaeta	20	0	0	0	10	2	32
P15	Feb-95	Diptera	Bezzia sp.	2	0	0	0	0	0	2
P15	Feb-95	Diptera	Chironomidae spp.	171	23	13	5	5	13	230
P15	Feb-96	Diptera	Bezzia sp.	0	5	0	0	0	0	5
P15	Feb-96	Diptera	Chironomidae spp.	21	21	1	4	94	26	167
P15	Feb-96	Oligochaeta	Oligochaeta	1	1	0	0	0	0	2
P15	Feb-96	Veneroida	Corbicula brandina	0	11	0	0	0	0	11
P15	Jun-95	Diptera	Bezzia sp.	0	0	0	0	0	1	1
P15	Jun-95	Diptera	Chaoborus sp.	1	3	2	0	0	0	6
P15	Jun-95	Diptera	Chironomidae spp.	15	73	45	10	29	11	183
P15	Jun-95	Oligochaeta	Oligochaeta	17	0	0	3	0	7	27
P15	Jun-96	Diptera	Bezzia sp.	0	0	0	0	1	0	1

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P15	Jun-96	Diptera	Chaoborus sp.	1	0	0	0	0	0	1
P15	Jun-96	Diptera	Chironomidae spp.	0	0	0	0	128	67	195
P15	Jun-96	Oligochaeta	Oligochaeta	2	0	3	0	2	2	9
P15	Oct-95	Diptera	Bezzia sp.	1	0	0	0	0	0	1
P15	Oct-95	Diptera	Chaoborus sp.	0	0	0	0	0	1	1
P15	Oct-95	Diptera	Chironomidae spp.	6	14	3	7	4	8	42
P15	Oct-95	Oligochaeta	Oligochaeta	2	0	0	0	0	0	2
P16	Apr-95	Diptera	Chironomidae spp.	2	1	0	0	0	1	4
P16	Apr-96	Diptera	Chaoborus sp.	0	1	1	0	0	0	2
P16	Apr-96	Diptera	Chironomidae spp.	0	1	0	0	0	0	1
P16	Apr-96	Veneroida	Corbicula brandina	0	0	5	0	0	0	5
P16	Aug-95	Diptera	Bezzia sp.	0	0	2	0	0	0	2
P16	Aug-96	Coleoptera	Stenopelmis sp.	0	0	2	0	0	0	2
P16	Aug-96	Veneroida	Corbicula brandina	0	0	1	0	0	0	1
P16	Dec-95	Diptera	Chironomidae spp.	1	0	1	5	4	0	11
P16	Dec-95	Oligochaeta	Oligochaeta	1	0	1	0	0	0	2
P16	Jun-95	Diptera	Chironomidae spp.	0	0	2	0	0	0	2
P16	Jun-95	Mesogastropoda	Lymnaea sp.	0	0	1	0	0	0	1
P16	Jun-95	Oligochaeta	Oligochaeta	5	0	0	0	0	0	5
P16	Jun-96	Diptera	Chaoborus sp.	0	1	0	0	0	0	1
P16	Oct-95	Diptera	Chironomidae spp.	0	1	0	0	0	0	1
P16	Oct-95	Oligochaeta	Oligochaeta	0	1	0	0	0	0	1
P17	Apr-96	Diptera	Bezzia sp.	0	1	1	0	0	0	2
P17	Apr-96	Diptera	Chironomidae spp.	7	6	7	13	6	7	46
P17	Apr-96	Ephemeroptera	Litobrancha sp.	0	1	0	0	0	0	1
P17	Apr-96	Oligochaeta	Oligochaeta	3	0	0	0	0	0	3
P17	Apr-96	Trichoptera	Ecnomus sp.	0	1	0	0	0	0	1
P17	Apr-96	Trichoptera	Phylocentropus sp.	0	2	0	0	0	1	3
P17	Apr-96	Veneroida	Corbicula brandina	0	0	1	0	0	0	1
P17	Aug-95	Diptera	Bezzia sp.	0	0	1	0	0	0	1
P17	Aug-95	Diptera	Chaoborus sp.	0	0	0	0	1	0	1
P17	Aug-95	Diptera	Chironomidae spp.	2	3	2	6	6	7	26
P17	Aug-95	Ephemeroptera	Litobrancha sp.	0	1	0	0	0	0	1
P17	Aug-96	Diptera	Bezzia sp.	0	0	0	1	1	1	3
P17	Aug-96	Diptera	Chaoborus sp.	0	0	0	0	1	0	1
P17	Aug-96	Diptera	Chironomidae spp.	1	0	0	1	0	0	2
P17	Aug-96	Ephemeroptera	Litobrancha sp.	5	0	0	0	0	0	5
P17	Aug-96	Veneroida	Corbicula brandina	0	0	0	2	0	0	2
P17	Dec-95	Diptera	Bezzia sp.	2	2	1	0	2	1	8
P17	Dec-95	Diptera	Chaoborus sp.	0	5	1	3	0	0	9
P17	Dec-95	Diptera	Chironomidae spp.	7	3	4	1	3	6	24
P17	Dec-95	Ephemeroptera	Caenis sp1	0	0	1	0	0	0	1
P17	Dec-95	Ephemeroptera	Litobrancha sp.	0	2	1	0	2	0	5
P17	Dec-95	Trichoptera	Ecnomus sp.	0	0	0	2	0	0	2
P17	Feb-96	Diptera	Bezzia sp.	0	1	2	0	0	1	4
P17	Feb-96	Diptera	Chironomidae spp.	3	6	3	5	2	2	21
P17	Feb-96	Ephemeroptera	Caenis sp2	0	0	0	0	1	0	1
P17	Feb-96	Ephemeroptera	Litobrancha sp.	0	0	1	0	5	2	8
P17	Feb-96	Oligochaeta	Oligochaeta	3	0	0	0	0	0	3
P17	Jun-96	Coleoptera	Cleptelmis sp.	1	0	0	0	1	0	2
P17	Jun-96	Diptera	Bezzia sp.	0	0	3	0	0	0	3
P17	Jun-96	Diptera	Chironomidae spp.	3	0	4	0	5	0	12
P17	Jun-96	Ephemeroptera	Centroptilum sp.	0	0	2	0	0	0	2
P17	Jun-96	Ephemeroptera	Litobrancha sp.	4	0	0	3	1	7	15
P17	Jun-96	Trichoptera	Amphipsyche meridiana	0	0	2	0	0	0	2
P17	Jun-96	Trichoptera	Ecnomus sp.	0	0	2	0	0	0	2
P17	Oct-95	Diptera	Chironomidae spp.	2	0	0	0	0	1	3
P17	Oct-95	Ephemeroptera	Caenis sp1	0	0	0	0	1	0	1
P17	Oct-95	Ephemeroptera	Litobrancha sp.	10	0	3	10	7	3	33
P17	Oct-95	Oligochaeta	Oligochaeta	0	1	0	0	0	0	1
P18	Apr-95	Diptera	Chaoborus sp.	19	71	1	16	21	73	201
P18	Apr-96	Diptera	Bezzia sp.	0	0	0	0	0	1	1
P18	Apr-96	Oligochaeta	Oligochaeta	1	0	8	0	0	2	11
P18	Aug-95	Diptera	Chironomidae spp.	1	1	6	7	8	3	26

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
P18	Aug-95	Odonata	Hagenius sp.	1	0	0	0	0	0	1
P18	Aug-96	Diptera	Bezzia sp.	1	0	2	1	0	0	4
P18	Aug-96	Diptera	Chironomidae spp.	1	3	2	1	3	0	10
P18	Aug-96	Ephemeroptera	Litobrancha sp.	3	1	1	1	1	0	7
P18	Dec-95	Diptera	Chaoborus sp.	1	5	1	0	1	0	8
P18	Dec-95	Diptera	Chironomidae spp.	0	0	0	9	0	0	9
P18	Dec-95	Ephemeroptera	Litobrancha sp.	0	0	0	3	0	0	3
P18	Dec-95	Trichoptera	Chimarra sp.	1	0	0	1	0	0	2
P18	Feb-95	Diptera	Chaoborus sp.	0	4	3	0	4	5	16
P18	Feb-96	Diptera	Chaoborus sp.	0	1	3	0	1	2	7
P18	Feb-96	Diptera	Chironomidae spp.	2	0	0	2	0	1	5
P18	Feb-96	Oligochaeta	Oligochaeta	1	0	0	0	1	0	2
P18	Jun-95	Diptera	Chaoborus sp.	4	8	17	9	105	28	171
P18	Jun-96	Diptera	Bezzia sp.	0	1	0	2	0	0	3
P18	Jun-96	Diptera	Chironomidae spp.	14	11	4	13	1	0	43
P18	Jun-96	Ephemeroptera	Litobrancha sp.	0	0	5	1	0	0	6
P18	Jun-96	Oligochaeta	Oligochaeta	0	0	0	0	1	3	4
P18	Jun-96	Trichoptera	Phylocentropus sp.	1	0	2	0	0	0	3
P18	Oct-95	Diptera	Bezzia sp.	0	0	0	1	0	0	1
P18	Oct-95	Diptera	Chironomidae spp.	6	4	6	13	5	1	35
P18	Oct-95	Ephemeroptera	Litobrancha sp.	1	0	0	0	0	1	2
P18	Oct-95	Oligochaeta	Oligochaeta	0	0	1	0	0	0	1
P18	Oct-95	Trichoptera	Ecnomus sp.	2	0	0	0	0	0	2
P18	Oct-95	Trichoptera	Macrostemum similior	15	0	0	0	0	0	15
P18	Oct-95	Trichoptera	Polycentropus sp.	0	0	0	0	0	1	1
P18	Oct-95	Veneroida	Corbicula brandina	0	0	0	1	0	0	1
P19	Apr-95	Diptera	Chaoborus sp.	411	354	332	356	154	291	1898
P19	Apr-96	Diptera	Chaoborus sp.	4	6	14	0	12	0	36
P19	Apr-96	Diptera	Chironomidae spp.	0	0	2	1	0	1	4
P19	Aug-95	Diptera	Bezzia sp.	1	0	0	0	0	0	1
P19	Aug-95	Diptera	Chaoborus sp.	0	0	6	0	1	0	7
P19	Aug-95	Diptera	Chironomidae spp.	0	0	2	2	0	0	4
P19	Aug-95	Oligochaeta	Oligochaeta	2	0	9	0	2	1	14
P19	Aug-95	Trichoptera	Ecnomus sp.	0	1	0	0	0	0	1
P19	Aug-96	Diptera	Bezzia sp.	1	1	0	0	8	1	11
P19	Aug-96	Diptera	Chironomidae spp.	0	0	0	1	0	0	1
P19	Aug-96	Trichoptera	Phylocentropus sp.	0	2	0	0	0	0	2
P19	Dec-95	Coleoptera	Stenelmis sp.	0	0	0	0	1	1	2
P19	Dec-95	Diptera	Chaoborus sp.	0	0	0	1	0	0	1
P19	Dec-95	Diptera	Chironomidae spp.	5	3	0	4	2	3	17
P19	Dec-95	Oligochaeta	Oligochaeta	0	1	5	0	1	2	9
P19	Feb-95	Diptera	Chaoborus sp.	3	6	13	27	18	15	82
P19	Feb-95	Diptera	Chironomidae spp.	0	1	0	1	1	0	3
P19	Feb-95	Ephemeroptera	Litobrancha sp.	0	1	0	0	0	0	1
P19	Feb-96	Diptera	Bezzia sp.	0	1	0	1	1	0	3
P19	Feb-96	Diptera	Chaoborus sp.	0	0	1	0	0	0	1
P19	Feb-96	Diptera	Chironomidae spp.	7	1	1	9	2	10	30
P19	Feb-96	Oligochaeta	Oligochaeta	0	0	0	0	0	1	1
P19	Jun-95	Diptera	Chaoborus sp.	19	27	48	53	7	17	171
P19	Jun-95	Ephemeroptera	Litobrancha sp.	2	1	0	0	0	0	3
P19	Jun-95	Trichoptera	Polycentropus sp.	0	1	2	0	0	0	3
P19	Jun-96	Coleoptera	Cleptelmis sp.	0	0	0	0	0	1	1
P19	Jun-96	Diptera	Chironomidae spp.	0	2	0	1	0	0	3
P19	Jun-96	Trichoptera	Phylocentropus sp.	0	0	1	0	0	0	1
P20	Apr-95	Diptera	Chaoborus sp.	329	316	21	222	232	338	1458
P20	Apr-96	Diptera	Bezzia sp.	0	0	0	1	0	0	1
P20	Apr-96	Diptera	Chaoborus sp.	13	1	2	0	1	0	17
P20	Apr-96	Diptera	Chironomidae spp.	0	1	0	2	0	7	10
P20	Aug-95	Ephemeroptera	Litobrancha sp.	0	1	0	4	2	4	11
P20	Aug-95	Oligochaeta	Oligochaeta	2	0	2	1	2	2	9
P20	Aug-96	Diptera	Bezzia sp.	3	0	0	3	0	0	6
P20	Aug-96	Diptera	Chironomidae spp.	3	0	0	1	0	0	4
P20	Aug-96	Trichoptera	Ecnomus sp.	0	0	0	0	1	0	1
P20	Aug-96	Trichoptera	Phylocentropus sp.	1	0	0	0	0	0	1

Appendix 3.2 (cont.)

Site	Month	Order	Species	Replicate no. 1	2	3	4	5	6	Total
P20	Dec-95	Coleoptera	Stenelmis sp.	0	0	0	0	0	1	1
P20	Dec-95	Diptera	Bezzia sp.	0	0	0	0	1	0	1
P20	Dec-95	Diptera	Chaoborus sp.	1	0	0	0	0	2	3
P20	Dec-95	Diptera	Chironomidae spp.	2	8	13	1	3	6	33
P20	Dec-95	Ephemeroptera	Litobrancha sp.	0	0	0	0	1	0	1
P20	Feb-95	Diptera	Chaoborus sp.	0	5	0	13	1	17	36
P20	Feb-96	Diptera	Bezzia sp.	0	0	0	0	0	1	1
P20	Feb-96	Diptera	Chaoborus sp.	0	0	3	3	0	0	6
P20	Feb-96	Diptera	Chironomidae spp.	4	7	3	0	4	1	19
P20	Feb-96	Ephemeroptera	Litobrancha sp.	0	0	0	1	1	0	2
P20	Feb-96	Oligochaeta	Oligochaeta	2	0	0	0	0	0	2
P20	Feb-96	Trichoptera	Phylocentropus sp.	0	0	0	0	1	0	1
P20	Jun-95	Coleoptera	Neocylloepus sp.	0	0	1	0	0	0	1
P20	Jun-95	Diptera	Bezzia sp.	1	0	0	0	0	0	1
P20	Jun-95	Diptera	Chaoborus sp.	16	23	30	9	52	17	147
P20	Jun-95	Diptera	Chironomidae spp.	2	0	5	1	2	5	15
P20	Jun-95	Hemiptera	Pentacola sp.	1	0	0	0	0	0	1
P20	Jun-95	Trichoptera	Polycentropus sp.	0	0	1	1	0	3	5
P20	Jun-96	Coleoptera	Cleptelmis sp.	0	0	0	0	0	1	1
P20	Jun-96	Diptera	Bezzia sp.	0	0	1	0	0	1	2
P20	Jun-96	Diptera	Chironomidae spp.	0	1	8	2	2	10	23
P20	Jun-96	Oligochaeta	Oligochaeta	0	0	0	0	0	1	1
P20	Jun-96	Trichoptera	Phylocentropus sp.	0	0	1	0	0	7	8
P20	Oct-95	Coleoptera	Stenelmis sp.	0	0	0	0	0	1	1
P20	Oct-95	Decapoda	Macrobrachium lanchestri	0	2	0	0	1	0	3
P20	Oct-95	Diptera	Chaoborus sp.	0	1	0	0	0	0	1
P20	Oct-95	Diptera	Chironomidae spp.	8	5	5	10	7	7	42
P20	Oct-95	Ephemeroptera	Caenis sp1	0	0	0	0	1	0	1
P20	Oct-95	Ephemeroptera	Litobrancha sp.	0	0	0	0	0	1	1
P21	Apr-95	Diptera	Chaoborus sp.	62	6	8	6	48	39	169
P21	Apr-96	Diptera	Bezzia sp.	0	0	0	2	0	0	2
P21	Apr-96	Diptera	Chaoborus sp.	0	0	1	0	0	0	1
P21	Apr-96	Diptera	Chironomidae spp.	1	0	9	0	6	0	16
P21	Apr-96	Oligochaeta	Oligochaeta	0	0	1	0	0	0	1
P21	Aug-95	Diptera	Bezzia sp.	0	0	0	0	1	0	1
P21	Aug-95	Diptera	Chaoborus sp.	0	0	1	0	0	3	4
P21	Aug-95	Diptera	Chironomidae spp.	3	0	1	0	2	0	6
P21	Aug-96	Diptera	Bezzia sp.	0	0	1	0	0	0	1
P21	Aug-96	Diptera	Chironomidae spp.	1	0	1	1	0	0	3
P21	Aug-96	Trichoptera	Phylocentropus sp.	0	1	0	0	0	0	1
P21	Dec-95	Diptera	Bezzia sp.	0	0	1	0	0	0	1
P21	Dec-95	Diptera	Chironomidae spp.	0	0	1	5	2	4	12
P21	Feb-95	Diptera	Chaoborus sp.	7	0	1	1	4	10	23
P21	Feb-95	Diptera	Chironomidae spp.	0	0	0	0	1	5	6
P21	Feb-95	Ephemeroptera	Caenis sp1	0	0	1	0	0	0	1
P21	Feb-96	Coleoptera	Cleptelmis sp.	0	1	0	0	0	0	1
P21	Feb-96	Diptera	Bezzia sp.	18	2	0	0	1	0	21
P21	Feb-96	Diptera	Chaoborus sp.	0	0	0	0	0	3	3
P21	Feb-96	Diptera	Chironomidae spp.	0	2	0	3	12	11	28
P21	Feb-96	Veneroida	Corbicula brandina	0	0	1	1	0	0	2
P21	Jun-95	Diptera	Bezzia sp.	0	0	0	4	0	0	4
P21	Jun-95	Diptera	Chironomidae spp.	3	1	6	9	4	3	26
P21	Jun-95	Mesogastropoda	Mekongia sp2	0	1	0	0	0	0	1
P21	Jun-95	Veneroida	Corbicula brandina	0	1	1	1	0	0	3
P21	Jun-96	Diptera	Chironomidae spp.	3	0	0	1	1	0	5
P21	Jun-96	Oligochaeta	Oligochaeta	2	0	0	6	0	0	8
P21	Jun-96	Trichoptera	Phylocentropus sp.	4	2	0	0	1	0	7
P21	Oct-95	Diptera	Bezzia sp.	5	0	0	0	0	0	5
P21	Oct-95	Diptera	Chaoborus sp.	0	1	31	0	7	1	40
P21	Oct-95	Diptera	Chironomidae spp.	5	7	1	20	2	4	39
P21	Oct-95	Ephemeroptera	Litobrancha sp.	1	0	0	0	1	2	4
P21	Oct-95	Oligochaeta	Oligochaeta	27	2	0	9	7	0	45
P21	Oct-95	Trichoptera	Polycentropus sp.	0	0	0	0	2	0	2

Appendix 3.3 Average water physicochemical values of the Pong catchment

Site code	Month	Water-temp (°C)	Velocity (m/sec)	Width (m)	Depth (m)	Discharge (m/sec)	pH	Alkalinity (mg/L)	EC (µS/cm)
P01	Apr-95	30.0	0.6	5.0	0.2	0.4	7.2	201	103.9
P02	Apr-95	31.4	0.3	3.0	0.2	0.2	7.2	165	334.0
P03	Apr-95	31.0	0.3	6.0	0.2	0.2	6.9	83	147.7
P04	Apr-95	31.9	0.2	20.0	0.2	0.6	8.4	141	286.0
P05	Apr-95	35.2	0.7	35.0	3.5	74.8	8.1	196	407.0
P06	Apr-95	30.5	0.1	22.0	1.7	2.8	7.4	104	208.0
P08	Apr-95	30.9	0.0	14.0	1.5	0.7	7.6	143	297.0
P09	Apr-95	27.4	0.0	58.0	9.0	18.0	7.4	88	228.0
P10	Apr-95	31.6	0.2	80.0	10.0	110.1	7.2	87	202.0
P11	Apr-95	31.4	0.4	51.0	0.7	9.8	7.8	91	231.0
P12	Apr-95	33.3	0.4	29.0	0.6	5.6	7.9	97	294.0
P13	Apr-95	34.1	0.1	49.0	5.8	16.9	7.6	90	300.0
P14	Apr-95	29.2	0.3	11.0	0.4	0.9	7.8	101	330.0
P15	Apr-95	30.7	0.1	23.0	0.6	0.7	8.1	131	570.0
P16	Apr-95	31.8	0.0	50.0	0.9	0.0	7.3	138	545.0
P18	Apr-95	33.5	0.1	53.0	6.1	16.9	7.8	86	287.0
P19	Apr-95	35.5	0.1	59.0	5.5	25.1	9.0	103	944.0
P20	Apr-95	33.8	0.1	61.0	6.8	33.5	9.5	109	1395.0
P21	Apr-95	33.6	0.2	39.0	3.3	22.1	9.0	109	1906.0
P01	Apr-96	30.2	0.7	9.7	0.3	1.6	8.0	82	167.5
P02	Apr-96	29.5	0.3	2.8	0.2	0.1	7.7	138	272.7
P03	Apr-96	28.5	0.6	4.8	0.4	0.9	8.0	114	240.2
P04	Apr-96	27.2	0.9	19.0	0.5	6.6	8.0	90	182.1
P05	Apr-96	29.0	0.2	43.0	0.4	2.4	7.8	76	176.3
P06	Apr-96	28.0	0.2	18.0	1.9	6.2	7.9	90	187.7
P07	Apr-96	27.4	0.2	28.0	2.8	14.5	7.8	76	162.5
P08	Apr-96	28.3	0.2	17.0	4.0	9.4	7.9	82	181.0
P09	Apr-96	25.0	0.2	69.0	6.1	57.3	7.9	82	171.0
P10	Apr-96	26.1	0.2	71.0	6.1	73.7	8.0	84	196.0
P11	Apr-96	27.7	0.3	39.0	0.7	6.2	8.4	82	193.8
P12	Apr-96	28.9	0.7	37.0	0.4	7.5	8.0	82	204.8
P13	Apr-96	33.1	0.2	58.0	3.2	30.0	8.0	82	198.8
P14	Apr-96	27.0	0.3	4.6	2.7	2.6	7.7	100	271.0
P15	Apr-96	31.1	0.1	23.0	1.3	3.3	7.6	114	520.0
P16	Apr-96	28.0	0.1	48.0	1.8	7.8	7.7	112	440.5
P17	Apr-96	29.8	0.2	59.0	2.7	26.8	7.8	76	230.0
P18	Apr-96	32.7	0.1	67.0	4.4	31.9	7.9	86	250.0
P19	Apr-96	34.3	0.1	63.0	3.6	15.6	8.3	94	1218.7
P20	Apr-96	31.1	0.1	62.0	2.8	12.1	8.2	90	1286.7
P21	Apr-96	30.5	0.1	46.0	1.1	3.4	8.1	92	1690.3
P01	Aug-95	24.9	1.3	18.0	1.2	25.6	8.1	56	157.3
P02	Aug-95	26.7	0.8	21.0	0.9	12.9	8.0	86	181.5
P03	Aug-95	26.0	0.8	22.0	1.5	22.7	8.0	82	176.2
P04	Aug-95	27.2	0.8	31.0	0.8	17.3	7.2	96	208.0
P05	Aug-95	28.1	0.6	49.0	8.1	207.5	7.2	80	179.7
P06	Aug-95	28.2	0.8	32.0	3.6	71.8	7.6	126	184.0
P08	Aug-95	28.7	1.0	24.0	8.0	147.8	7.2	94	214.0
P09	Aug-95	28.7	0.6	79.0	8.7	331.0	7.2	88	184.4
P10	Aug-95	29.0	0.6	81.0	13.2	514.9	7.5	84	188.7
P11	Aug-95	29.3	0.5	73.0	6.2	178.8	8.0	86	187.0
P12	Aug-95	29.0	1.0	82.0	6.2	375.9	7.2	82	176.0
P13	Aug-95	29.5	0.8	77.0	8.3	435.0	7.1	82	176.6

Appendix 3.3 (cont.)

Sitc code	Month	Water-temp (°C)	Velocity (m/sec)	Width (m)	Depth (m)	Discharge (m/sec)	pH	Alkalinity (mg/L)	EC (µS/cm)
P14	Aug-95	29.7	0.6	14.0	1.9	13.1	7.0	66	177.0
P15	Aug-95	30.2	0.7	21.0	2.4	28.9	7.2	84	350.0
P16	Aug-95	31.0	0.3	76.0	1.8	28.0	7.7	86	352.0
P17	Aug-95	29.7	1.0	69.0	10.2	563.0	7.5	80	176.3
P18	Aug-95	29.6	1.0	71.0	9.3	541.5	7.5	72	188.0
P19	Aug-95	29.8	1.0	77.0	10.1	645.5	7.1	42	386.0
P20	Aug-95	30.0	1.0	81.0	9.1	641.3	7.4	42	325.0
P21	Aug-95	29.6	1.3	87.0	7.1	648.6	7.8	46	311.0
P01	Aug-96	27.0	1.2	19.0	0.3	5.1	9.6	74	170.0
P02	Aug-96	24.2	0.9	24.0	0.3	5.5	9.4	88	190.9
P03	Aug-96	25.2	1.2	25.0	0.5	11.9	8.7	86	184.2
P04	Aug-96	28.0	0.8	31.0	0.3	6.2	8.6	96	229.0
P05	Aug-96	28.2	0.7	37.0	4.2	88.3	7.5	94	207.8
P06	Aug-96	25.2	0.2	21.0	1.6	5.1	9.2	104	230.3
P07	Aug-96	27.4	0.2	35.0	2.7	12.9	9.0	114	307.7
P08	Aug-96	31.0	0.0	23.0	1.6	0.0	9.5	110	248.8
P09	Aug-96	27.4	0.2	76.0	8.6	128.6	6.5	82	197.8
P10	Aug-96	27.0	0.3	81.0	6.7	143.1	6.5	84	234.5
P11	Aug-96	26.0	0.2	32.0	0.8	4.4	6.8	84	219.8
P12	Aug-96	27.0	0.4	28.0	0.4	3.6	7.7	86	220.3
P13	Aug-96	26.8	0.2	72.0	2.1	29.6	7.8	88	242.0
P14	Aug-96	26.2	0.6	5.7	1.1	3.2	7.7	96	262.7
P15	Aug-96	25.9	0.3	32.0	1.0	7.0	7.5	98	405.5
P16	Aug-96	26.4	0.2	39.0	2.0	13.3	7.3	100	399.7
P17	Aug-96	27.4	0.2	75.0	3.4	31.4	20.7	86	245.0
P18	Aug-96	28.1	0.2	81.0	4.7	77.0	7.5	66	276.8
P19	Aug-96	27.2	0.2	74.0	3.2	29.7	7.9	72	265.5
P20	Aug-96	26.9	0.3	61.0	3.4	45.3	8.0	82	238.3
P21	Aug-96	26.0	0.5	41.0	1.2	19.0	8.0	88	205.8
P01	Dec-95	22.1	0.9	7.0	0.6	2.3	8.3	152	308.0
P02	Dec-95	22.5	1.2	11.0	0.1	1.3	8.2	260	553.0
P03	Dec-95	22.3	1.4	15.0	0.3	5.0	8.5	186	381.0
P04	Dec-95	20.8	0.8	25.0	0.2	2.6	8.3	208	414.0
P05	Dec-95	24.9	0.5	36.0	3.5	52.6	8.3	186	382.0
P06	Dec-95	21.4	0.2	36.0	1.7	12.8	8.2	152	313.0
P07	Dec-95	21.4	0.2	26.0	3.0	10.9	8.3	152	315.0
P08	Dec-95	23.6	0.1	24.0	2.5	4.1	8.4	160	325.0
P09	Dec-95	23.9	0.2	52.0	6.3	45.1	8.5	88	182.7
P10	Dec-95	24.0	0.4	56.0	8.0	154.1	8.0	86	220.0
P11	Dec-95	25.6	0.4	47.0	0.6	10.9	8.8	90	238.0
P12	Dec-95	25.8	0.5	39.0	0.7	12.2	8.0	96	265.0
P13	Dec-95	25.1	0.2	36.0	4.4	92.0	8.0	92	305.0
P14	Dec-95	26.4	0.1	7.6	0.4	0.2	7.8	124	1795.0
P15	Dec-95	24.7	0.1	19.0	1.0	1.4	7.2	178	895.0
P16	Dec-95	24.5	0.1	32.0	1.2	2.7	8.1	168	882.0
P17	Dec-95	24.7	0.2	38.0	4.0	20.7	8.0	96	311.0
P18	Dec-95	24.5	0.2	48.0	5.0	50.1	8.4	94	307.0
P19	Dec-95	24.5	0.2	47.0	6.3	40.7	7.8	92	637.0
P20	Dec-95	25.0	0.3	48.0	3.4	44.9	7.9	104	629.0
P21	Dec-95	25.4	0.6	52.0	2.0	50.7	7.9	94	646.0
P01	Feb-95	27.2	0.7	6.5	0.3	0.9	7.6	191	409.0
P02	Feb-95	27.8	0.5	3.7	0.4	0.6	6.7	173	398.0
P03	Feb-95	27.0	0.4	25.0	0.2	1.5	7.1	188	445.0

Appendix 3.3 (cont.)

Sitc code	Month	Water-temp (°C)	Velocity (m/sec)	Width (m)	Depth (m)	Discharge (m/sec)	pH	Alkalinity (mg/L)	EC (μS/cm)
P04	Feb-95	29.1	0.2	15.0	0.2	0.4	8.1	143	365.0
P05	Feb-95	31.0	0.3	25.0	7.2	35.8	9.1	90	225.0
P06	Feb-95	27.0	0.1	29.0	1.8	4.1	6.9	79	188.0
P08	Feb-95	29.4	0.0	27.0	2.8	1.6	7.8	184	297.0
P09	Feb-95	25.8	0.1	61.0	8.5	42.6	7.3	61	177.0
P10	Feb-95	27.3	0.0	87.0	11.3	21.8	7.3	68	185.0
P11	Feb-95	28.4	0.3	51.0	1.0	10.3	7.4	66	195.0
P12	Feb-95	30.9	0.3	26.0	0.5	2.4	7.4	77	234.0
P13	Feb-95	30.2	0.0	52.0	6.6	5.7	7.8	73	320.0
P14	Feb-95	28.1	0.3	15.0	1.1	4.0	6.9	67	293.0
P15	Feb-95	25.7	0.0	28.0	1.2	1.1	7.2	78	399.0
P16	Feb-95	26.7	0.0	41.0	1.1	0.0	7.1	80	394.0
P18	Feb-95	27.1	0.4	63.0	7.8	146.3	7.6	71	359.0
P19	Feb-95	26.8	0.1	63.0	6.4	26.5	7.9	94	1047.0
P20	Feb-95	28.2	0.1	71.0	7.9	31.4	8.3	95	1157.0
P21	Feb-95	27.8	0.6	42.0	4.5	97.9	8.1	85	1640.0
P01	Feb-96	24.6	0.2	11.0	0.1	0.3	8.4	192	332.8
P02	Feb-96	25.5	0.2	8.0	0.1	0.1	7.9	212	394.3
P03	Feb-96	24.2	0.5	12.0	0.2	0.8	8.4	226	397.3
P04	Feb-96	25.0	0.1	26.0	0.2	0.4	8.5	196	365.0
P05	Feb-96	25.3	0.2	43.0	3.5	23.9	8.8	190	351.3
P06	Feb-96	22.9	0.3	28.0	1.1	8.4	8.0	74	138.1
P07	Feb-96	23.4	0.2	28.0	2.5	9.7	7.9	82	153.4
P08	Feb-96	23.2	0.2	32.0	2.8	12.9	8.0	114	212.4
P09	Feb-96	24.3	0.3	69.0	8.9	188.3	8.3	88	168.5
P10	Feb-96	23.1	0.3	71.0	9.5	198.6	8.1	88	201.1
P11	Feb-96	22.6	0.4	47.0	1.1	19.7	8.0	110	177.6
P12	Feb-96	25.5	0.5	46.0	1.8	39.7	8.6	88	187.1
P13	Feb-96	24.9	0.2	55.0	4.8	36.8	8.2	92	210.5
P14	Feb-96	25.2	0.4	6.0	0.3	0.7	7.8	94	290.3
P15	Feb-96	22.8	0.1	32.0	1.4	3.1	7.8	126	476.0
P16	Feb-96	24.6	0.1	47.0	1.7	8.4	8.1	84	463.5
P17	Feb-96	25.1	0.1	67.0	3.5	27.2	8.4	94	219.3
P18	Feb-96	27.3	0.2	58.0	8.1	69.2	8.1	88	215.8
P19	Feb-96	27.5	0.4	46.0	4.7	71.8	8.5	104	951.3
P20	Feb-96	26.5	0.2	48.0	6.4	45.2	8.5	237	1251.7
P21	Feb-96	26.3	0.2	28.0	1.7	6.7	8.4	106	1262.3
P01	Jun-95	31.1	0.7	11.0	0.2	1.3	7.5	56	115.0
P02	Jun-95	31.4	0.5	5.2	0.2	0.4	7.3	134	258.0
P03	Jun-95	32.4	1.3	12.8	0.4	5.9	7.2	86	172.0
P04	Jun-95	31.6	1.0	43.0	0.7	25.7	7.8	106	206.0
P05	Jun-95	32.9	0.1	38.0	2.0	4.7	8.3	136	280.0
P06	Jun-95	29.9	0.4	25.5	2.1	16.8	7.5	88	178.6
P08	Jun-95	30.4	0.1	27.0	1.9	6.5	7.8	92	198.2
P09	Jun-95	31.3	0.3	67.0	6.3	91.8	8.4	88	181.9
P10	Jun-95	33.1	0.1	71.0	12.3	96.5	7.6	94	250.0
P11	Jun-95	31.3	0.2	51.0	2.7	21.6	7.5	92	263.0
P12	Jun-95	31.7	0.4	36.0	4.8	65.9	7.5	96	215.0
P13	Jun-95	31.9	0.2	54.0	3.4	31.6	6.7	76	270.0
P14	Jun-95	31.1	0.4	5.1	0.8	1.3	7.1	82	319.0
P15	Jun-95	32.1	0.1	31.0	0.7	1.8	7.4	116	674.0
P16	Jun-95	32.8	0.0	62.0	0.8	0.0	7.4	108	707.0
P18	Jun-95	31.7	0.3	70.0	7.2	114.0	7.2	80	368.0

Appendix 3.3 (cont.)

Sitc code	**Month**	**Water-temp** (°C)	**Velocity** (m/sec)	**Width** (m)	**Depth** (m)	**Discharge** (m/sec)	**pH**	**Alkalinity** (mg/L)	**EC** (μS/cm)
P19	Jun-95	37.1	0.2	69.0	6.1	54.3	8.0	90	385.0
P20	Jun-95	32.9	0.3	70.0	4.2	74.2	7.8	80	340.0
P21	Jun-95	31.8	0.4	46.0	2.8	42.6	7.9	76	246.0
P01	Jun-96	30.0	1.0	13.0	0.4	4.3	7.5	56	120.2
P02	Jun-96	30.0	0.5	4.8	0.2	0.5	7.7	202	332.8
P03	Jun-96	28.3	0.8	12.0	0.4	3.1	7.9	86	158.9
P04	Jun-96	29.2	0.4	22.0	0.4	2.9	8.2	98	174.4
P05	Jun-96	29.6	0.1	42.0	2.3	10.8	8.1	74	146.2
P06	Jun-96	28.4	0.4	32.0	2.1	20.7	7.3	92	187.4
P07	Jun-96	28.9	0.3	24.0	3.0	17.8	8.3	108	229.2
P08	Jun-96	29.1	0.2	23.0	2.8	12.8	8.2	96	194.5
P09	Jun-96	29.2	0.2	71.0	8.8	98.3	8.2	92	187.6
P10	Jun-96	30.3	0.2	73.0	10.8	115.2	8.4	98	261.8
P11	Jun-96	30.4	0.2	54.0	1.8	18.3	7.7	102	266.8
P12	Jun-96	30.1	0.4	39.0	3.5	46.7	7.7	86	224.5
P13	Jun-96	32.0	0.4	39.0	4.0	49.6	7.2	90	263.3
P14	Jun-96	31.1	0.4	5.7	0.8	1.4	7.3	102	297.5
P15	Jun-96	31.1	0.1	34.0	0.9	3.2	7.6	126	596.7
P16	Jun-96	31.0	0.1	49.0	0.8	2.5	7.6	130	710.7
P17	Jun-96	29.6	0.6	58.0	3.0	86.5	8.1	94	172.1
P18	Jun-96	31.2	0.4	67.0	4.3	105.5	8.1	78	189.1
P19	Jun-96	33.1	0.2	33.0	4.0	16.0	8.4	62	288.8
P20	Jun-96	31.4	0.2	32.0	4.0	16.7	8.0	64	321.5
P21	Jun-96	31.3	0.3	21.0	1.8	9.8	8.1	82	353.2
P01	Oct-95	24.9	1.3	17.0	1.1	20.8	8.5	104	171.0
P02	Oct-95	27.2	1.0	7.0	0.9	5.0	8.0	126	246.0
P03	Oct-95	25.6	0.8	18.0	0.5	6.5	8.1	162	195.3
P04	Oct-95	27.3	1.3	17.0	0.4	6.6	8.2	110	221.0
P05	Oct-95	27.4	0.1	28.0	4.6	8.6	8.4	108	217.0
P06	Oct-95	29.2	1.7	35.0	3.9	191.3	7.1	116	227.0
P07	Oct-95	29.2	0.9	31.0	5.4	123.7	8.0	120	235.0
P08	Oct-95	28.2	0.8	22.0	7.5	101.6	8.0	102	195.2
P09	Oct-95	28.6	0.5	68.0	7.9	221.8	8.2	88	172.5
P10	Oct-95	28.9	0.6	71.0	9.6	328.3	8.2	84	193.1
P11	Oct-95	29.6	0.9	42.0	3.4	109.3	8.4	82	194.9
P12	Oct-95	29.0	0.8	51.0	5.7	203.5	8.0	84	184.5
P13	Oct-95	30.9	0.6	50.0	8.6	231.2	8.1	86	107.9
P14	Oct-95	29.5	0.1	15.0	2.0	1.9	7.6	80	196.3
P15	Oct-95	30.0	0.2	23.0	2.8	8.5	7.5	98	350.0
P16	Oct-95	31.6	0.1	78.0	4.0	20.5	8.1	92	330.0
P17	Oct-95	28.3	0.3	53.0	9.2	131.1	7.6	86	183.7
P18	Oct-95	29.7	0.1	65.0	7.3	31.9	7.8	88	214.0
P19	Oct-95	29.6	0.4	74.0	9.1	223.6	8.0	56	261.0
P20	Oct-95	29.5	0.8	79.0	8.9	7.7	8.0	60	261.0
P21	Oct-95	29.2	0.8	82.0	9.0	502.1	8.0	60	263.0

Appendix 3.3 (cont.)

Site code	Month	Turbi-dity (mg/L)	TDS (mg/L)	TSS (mg/L)	PO4 (mg/L)	NO3 (mg/L)	DO (mg/L)	BOD (mg/L)	Cl (mg/L)	SO4 (mg/L)
P01	Apr-95	500.0	85.0	2303.0	0.02	1.49	4.2	10.1	-	-
P02	Apr-95	10.5	263.0	2.8	0.04	0.69	7.3	3.2	-	-
P03	Apr-95	900.0	120.0	2304.0	ND	1.72	4.3	10.1	-	-
P04	Apr-95	3.2	205.0	4.0	ND	0.37	9.0	2.9	-	-
P05	Apr-95	10.0	324.0	16.5	0.02	0.31	6.4	4.8	-	-
P06	Apr-95	8.5	170.0	2.3	0.10	0.87	5.9	2.5	-	-
P08	Apr-95	54.0	250.0	59.0	0.18	0.38	4.1	3.8	-	-
P09	Apr-95	3.7	161.0	3.2	0.02	0.45	2.7	2.6	-	-
P10	Apr-95	5.4	186.0	10.8	0.07	0.44	5.9	7.3	-	-
P11	Apr-95	2.5	218.0	3.6	0.04	0.67	8.6	6.1	-	-
P12	Apr-95	6.9	249.0	7.6	0.02	0.75	8.4	6.8	-	-
P13	Apr-95	4.5	284.0	4.0	0.02	0.81	6.1	8.5	-	-
P14	Apr-95	14.0	210.0	9.2	0.04	0.77	0.5	19.1	-	-
P15	Apr-95	67.0	310.0	99.2	0.18	0.84	1.4	25.2	-	-
P16	Apr-95	15.0	375.0	16.4	0.18	1.12	3.6	29.4	-	-
P18	Apr-95	23.0	193.0	54.0	0.02	0.86	4.1	14.8	-	-
P19	Apr-95	8.9	617.0	10.4	0.02	0.93	8.1	5.3	-	-
P20	Apr-95	10.1	872.0	14.8	0.02	1.03	6.8	4.9	-	-
P21	Apr-95	6.0	987.0	11.2	ND	1.10	5.6	6.2	-	-
P01	Apr-96	127.6	112.2	138.5	0.20	0.40	6.8	1.4	3.2	26.0
P02	Apr-96	23.0	181.7	68.5	0.50	3.50	5.5	1.9	6.6	45.1
P03	Apr-96	164.6	160.1	399.5	0.10	1.10	6.4	1.5	5.2	40.4
P04	Apr-96	387.0	126.2	319.0	0.50	1.10	6.7	1.2	6.2	18.9
P05	Apr-96	249.0	117.5	136.0	0.40	4.50	4.9	1.3	7.7	31.8
P06	Apr-96	63.3	125.1	74.5	0.50	0.50	6.1	1.2	4.3	14.1
P07	Apr-96	99.0	108.5	69.5	0.50	0.60	6.5	1.6	4.7	15.7
P08	Apr-96	240.0	120.6	136.0	0.60	0.80	6.4	1.1	8.8	32.5
P09	Apr-96	4.8	113.9	3.0	0.02	0.10	4.4	1.4	6.7	7.0
P10	Apr-96	3.5	130.4	3.0	0.02	0.10	3.1	1.9	13.5	7.7
P11	Apr-96	2.4	129.2	2.0	0.04	1.40	7.2	1.0	14.7	7.3
P12	Apr-96	24.2	136.6	21.0	0.90	0.30	7.0	0.8	17.8	12.2
P13	Apr-96	25.5	132.6	8.0	0.04	0.30	6.4	1.4	27.9	13.1
P14	Apr-96	18.1	177.4	10.5	0.02	0.40	3.7	1.9	37.2	13.0
P15	Apr-96	34.6	346.7	26.5	0.10	0.50	2.7	6.7	101.3	20.7
P16	Apr-96	16.7	292.8	15.5	0.80	0.60	3.6	4.3	78.8	13.6
P17	Apr-96	40.2	152.7	23.5	0.04	0.30	6.2	2.3	22.7	14.7
P18	Apr-96	16.2	166.8	10.7	0.10	0.20	6.1	3.4	40.0	10.1
P19	Apr-96	23.4	811.0	9.0	0.02	0.10	7.1	1.8	405.0	18.3
P20	Apr-96	10.1	857.3	8.3	0.02	0.07	7.4	1.7	426.0	16.2
P21	Apr-96	11.9	1128.3	11.3	0.02	0.08	6.1	1.6	537.6	19.9
P01	Aug-95	69.0	126.4	108.3	ND	ND	9.3	1.3	5.7	10.8
P02	Aug-95	82.0	144.7	67.0	0.14	ND	8.5	1.3	7.3	15.3
P03	Aug-95	85.0	140.7	101.0	0.04	ND	8.8	1.0	8.0	13.0
P04	Aug-95	81.0	164.8	113.6	0.02	ND	9.8	1.3	8.0	13.2
P05	Aug-95	75.0	143.4	22.7	ND	ND	6.9	1.2	8.2	14.6
P06	Aug-95	58.0	146.7	68.0	0.04	ND	7.6	8.6	7.3	10.6
P08	Aug-95	98.0	169.4	130.8	0.10	ND	6.9	1.2	14.4	12.8
P09	Aug-95	10.0	146.9	8.2	0.02	ND	7.3	1.3	10.4	5.7
P10	Aug-95	13.0	150.2	7.6	0.24	ND	6.6	2.0	13.1	7.3
P11	Aug-95	11.0	148.9	8.0	0.02	ND	9.6	2.3	14.0	7.5
P12	Aug-95	17.0	140.6	26.2	ND	ND	7.9	1.5	13.4	9.7

Appendix 3.3 (cont.)

Site code	Month	Turbi-dity (mg/L)	TDS (mg/L)	TSS (mg/L)	PO4 (mg/L)	NO3 (mg/L)	DO (mg/L)	BOD (mg/L)	Cl (mg/L)	SO4 (mg/L)
P13	Aug-95	43.0	141.0	54.2	ND	ND	7.4	1.9	1.6	12.4
P14	Aug-95	28.0	141.4	18.6	0.04	ND	3.2	1.8	22.8	13.8
P15	Aug-95	41.0	272.3	22.5	0.24	1.50	4.5	3.1	67.6	16.5
P16	Aug-95	39.0	273.8	29.6	0.24	2.00	2.3	3.0	68.6	17.6
P17	Aug-95	56.0	140.8	22.3	0.02	ND	4.8	1.7	25.0	13.7
P18	Aug-95	39.0	149.7	46.0	ND	0.50	4.5	1.5	25.3	6.9
P19	Aug-95	375.0	299.4	150.5	0.18	ND	5.5	2.3	95.7	19.7
P20	Aug-95	370.0	253.3	175.0	0.02	ND	5.7	1.2	111.5	19.6
P21	Aug-95	360.0	242.7	132.0	0.04	ND	4.6	1.3	116.7	18.5
P01	Aug-96	52.0	112.2	53.0	ND	0.20	6.2	2.9	5.1	14.4
P02	Aug-96	350.0	126.0	245.0	ND	0.30	6.1	2.6	6.3	32.6
P03	Aug-96	32.5	121.5	35.0	0.02	0.20	6.1	8.2	5.7	14.0
P04	Aug-96	83.0	151.1	148.0	ND	0.40	6.1	8.2	9.1	16.9
P05	Aug-96	260.0	137.2	102.5	0.02	0.30	7.4	2.6	5.2	21.4
P06	Aug-96	26.0	152.0	15.5	ND	0.10	5.9	1.7	6.3	12.6
P07	Aug-96	33.0	203.1	41.0	0.02	0.30	6.0	2.1	3.8	10.2
P08	Aug-96	86.0	164.2	69.0	0.02	0.20	.	2.6	7.6	17.8
P09	Aug-96	11.0	130.6	32.5	ND	0.20	7.3	4.5	7.0	10.2
P10	Aug-96	5.0	154.8	7.0	ND	0.30	5.2	2.6	11.6	6.3
P11	Aug-96	5.2	145.1	5.5	0.02	0.20	6.9	1.1	12.5	5.8
P12	Aug-96	15.5	145.4	34.5	0.07	0.30	7.5	1.7	13.2	10.2
P13	Aug-96	18.0	159.7	37.0	0.07	0.30	6.5	1.4	21.6	13.4
P14	Aug-96	19.0	173.4	25.0	0.07	0.30	5.2	2.4	22.3	11.5
P15	Aug-96	26.3	267.6	28.0	0.04	3.00	4.5	3.4	58.7	10.0
P16	Aug-96	29.7	263.8	33.0	0.07	4.10	3.9	4.0	65.5	10.7
P17	Aug-96	16.8	161.7	15.5	0.04	0.50	6.0	1.7	25.9	8.1
P18	Aug-96	14.5	182.7	16.5	ND	0.20	5.8	1.8	26.7	18.9
P19	Aug-96	16.6	175.2	15.5	ND	0.30	6.2	0.8	36.7	17.2
P20	Aug-96	17.0	157.3	18.0	ND	0.20	6.5	1.6	24.0	16.4
P21	Aug-96	15.6	135.9	18.5	ND	0.40	6.7	1.2	36.6	8.3
P01	Dec-95	5.9	212.0	7.2	0.04	0.05	8.4	1.2	6.0	4.8
P02	Dec-95	6.4	354.0	3.2	0.14	0.03	9.8	4.5	11.0	4.1
P03	Dec-95	5.2	232.0	8.8	ND	0.03	8.0	2.4	10.1	8.5
P04	Dec-95	13.3	230.0	8.4	0.02	0.10	8.1	1.4	9.3	10.8
P05	Dec-95	12.8	210.0	9.2	0.02	0.08	6.9	1.2	8.8	9.8
P06	Dec-95	31.3	152.0	5.2	0.02	0.50	7.5	7.9	6.3	9.9
P07	Dec-95	16.1	156.0	9.2	0.02	0.30	7.5	1.0	8.1	6.3
P08	Dec-95	16.5	168.0	13.6	0.02	0.20	7.6	2.4	10.7	4.2
P09	Dec-95	5.3	92.0	9.2	0.02	0.06	7.3	1.5	10.3	5.4
P10	Dec-95	4.6	112.0	5.6	0.04	0.04	5.2	1.0	15.3	5.9
P11	Dec-95	2.5	130.0	1.5	0.02	0.30	12.2	1.0	21.5	8.5
P12	Dec-95	14.1	150.0	16.4	0.02	0.20	8.0	0.9	25.0	11.1
P13	Dec-95	13.7	148.0	18.4	0.02	0.07	7.6	2.4	38.2	12.0
P14	Dec-95	22.6	1880.0	48.4	0.02	1.50	13.2	1.8	892.0	11.5
P15	Dec-95	38.8	480.0	97.2	1.20	0.70	0.9	18.5	161.0	22.6
P16	Dec-95	32.7	434.0	51.2	0.70	1.50	10.9	17.8	166.0	19.8
P17	Dec-95	11.2	166.0	68.8	ND	0.05	10.0	2.6	38.8	11.0
P18	Dec-95	21.2	170.0	28.0	0.02	0.10	10.2	3.9	38.6	11.5
P19	Dec-95	12.8	396.0	27.6	0.02	0.30	7.7	1.0	139.0	13.2
P20	Dec-95	15.1	366.0	30.0	0.24	0.30	7.9	0.8	134.0	12.6
P21	Dec-95	13.6	412.0	52.0	0.10	0.30	7.5	1.0	137.2	13.5

Appendix 3.3 (cont.)

Site code	Month	Turbi-dity (mg/L)	TDS (mg/L)	TSS (mg/L)	PO4 (mg/L)	NO3 (mg/L)	DO (mg/L)	BOD (mg/L)	Cl (mg/L)	SO4 (mg/L)
P01	Feb-95	4.9	300.0	2.0	0.02	0.56	9.0	6.6	-	-
P02	Feb-95	23.0	263.0	15.1	0.02	0.58	5.6	3.0	-	-
P03	Feb-95	3.1	307.0	1.2	ND	0.62	8.4	2.7	-	-
P04	Feb-95	4.9	244.0	5.6	0.02	0.54	8.5	3.2	-	-
P05	Feb-95	33.5	152.0	338.5	0.02	0.57	15.6	5.8	-	-
P21	Jun-95	405.0	200.0	219.6	0.02	0.30	5.8	4.5	-	-
P01	Jun-96	200.0	80.2	228.5	0.02	0.30	7.2	1.0	5.6	21.5
P02	Jun-96	26.0	221.5	23.5	0.02	0.70	5.6	0.9	9.2	4.9
P03	Jun-96	100.0	105.8	212.5	ND	0.30	6.6	3.3	6.8	26.8
P04	Jun-96	350.0	115.9	305.0	0.14	0.40	6.8	1.9	6.5	29.5
P05	Jun-96	128.0	97.3	274.5	0.02	1.70	5.1	3.3	8.0	22.1
P06	Jun-96	72.0	124.9	89.0	ND	0.20	7.3	1.4	6.1	21.2
P07	Jun-96	53.0	152.6	63.0	ND	0.20	7.1	2.5	8.2	10.5
P08	Jun-96	81.0	129.6	73.0	0.04	0.30	6.5	1.1	5.5	15.1
P09	Jun-96	8.5	167.0	8.5	ND	0.10	6.2	1.5	6.6	7.2
P10	Jun-96	7.8	233.0	6.5	ND	0.20	5.3	1.7	11.0	7.1
P11	Jun-96	6.5	208.1	8.0	0.02	0.50	6.2	1.7	11.4	7.5
P12	Jun-96	15.0	193.1	12.5	ND	0.60	5.2	1.8	8.7	6.8
P13	Jun-96	27.5	226.5	30.0	0.02	0.20	4.2	1.4	9.1	14.2
P14	Jun-96	15.0	258.8	13.0	0.02	0.30	4.5	1.2	54.2	15.6
P15	Jun-96	25.5	519.1	32.0	0.30	0.70	3.5	10.5	163.9	20.9
P16	Jun-96	24.0	611.2	38.5	0.40	1.10	2.3	12.8	183.0	20.8
P17	Jun-96	27.0	115.0	25.5	0.04	0.70	6.7	1.6	9.2	5.9
P18	Jun-96	33.0	126.1	22.5	0.02	0.80	6.8	1.9	14.4	5.6
P19	Jun-96	430.0	192.2	218.0	0.04	0.30	5.8	0.5	58.1	21.2
P20	Jun-96	400.0	214.5	153.0	0.04	0.40	6.0	1.0	77.3	17.6
P21	Jun-96	395.0	235.3	165.5	0.04	0.40	6.6	0.9	85.0	15.4
P01	Oct-95	46.0	156.0	37.0	ND	0.10	7.5	1.2	5.9	7.2
P02	Oct-95	37.0	238.0	33.0	ND	0.20	6.1	1.4	6.9	7.2
P03	Oct-95	55.0	188.0	58.0	ND	0.10	6.1	1.9	7.8	6.3
P04	Oct-95	42.0	108.0	39.8	0.02	ND	7.0	0.5	9.3	7.9
P05	Oct-95	35.0	156.0	28.5	0.30	ND	6.4	0.5	8.3	8.2
P06	Oct-95	27.0	193.8	166.0	0.02	0.10	5.7	1.4	4.6	6.8
P07	Oct-95	34.0	185.2	164.0	0.02	0.10	6.6	1.3	7.6	6.2
P08	Oct-95	22.5	124.0	21.5	ND	ND	4.6	0.8	10.8	4.7
P09	Oct-95	3.0	140.0	5.6	0.10	0.10	5.1	1.7	10.5	6.3
P10	Oct-95	3.5	154.0	4.4	0.04	0.10	4.4	1.2	16.6	8.2
P11	Oct-95	6.8	142.0	12.5	0.04	0.20	7.3	1.5	14.9	7.5
P12	Oct-95	39.0	148.0	58.3	0.07	0.40	6.3	1.1	14.1	17.5
P13	Oct-95	12.0	140.0	37.8	0.02	0.80	5.2	1.3	12.7	10.3
P14	Oct-95	12.0	160.0	10.5	0.02	0.05	2.7	1.1	19.0	7.9
P15	Oct-95	25.0	2.6	16.5	0.07	1.40	2.6	2.5	60.4	8.2
P16	Oct-95	28.0	236.0	36.5	0.14	1.20	2.1	4.6	58.1	8.8
P17	Oct-95	11.5	132.0	22.8	0.04	0.20	4.4	0.9	13.0	10.3
P18	Oct-95	20.0	162.0	29.8	0.10	0.50	2.8	2.1	24.4	10.4
P19	Oct-95	26.0	180.0	37.8	0.02	0.20	3.9	0.6	55.2	9.8
P20	Oct-95	27.0	230.0	47.5	ND	0.10	3.9	0.9	52.2	12.6
P21	Oct-95	18.0	160.0	29.3	0.07	0.10	3.5	1.2	58.1	8.5
P01	Feb-95	4.9	300.0	2.0	0.02	0.56	9.0	6.6	-	-
P02	Feb-95	23.0	263.0	15.1	0.02	0.58	5.6	3.0	-	-
P03	Feb-95	3.1	307.0	1.2	ND	0.62	8.4	2.7	-	-
P04	Feb-95	4.9	244.0	5.6	0.02	0.54	8.5	3.2	-	-

Appendix 3.3 (cont.)

Site code	Month	Turbi-dity (mg/L)	TDS (mg/L)	TSS (mg/L)	PO4 (mg/L)	NO3 (mg/L)	DO (mg/L)	BOD (mg/L)	Cl (mg/L)	SO4 (mg/L)
P05	Feb-95	33.5	152.0	338.5	0.02	0.57	15.6	5.8	-	-
P06	Feb-95	10.0	134.0	6.0	0.10	0.46	6.8	2.9	-	-
P08	Feb-95	12.0	182.0	13.4	0.07	0.58	5.8	3.6	-	-
P09	Feb-95	3.6	102.0	6.0	0.14	0.50	4.8	4.0	-	-
P10	Feb-95	3.0	179.0	4.9	0.03	0.53	6.4	4.8	-	-
P11	Feb-95	3.3	189.0	1.4	0.02	0.60	6.7	3.5	-	-
P12	Feb-95	13.0	227.0	9.6	0.02	0.52	9.1	1.9	-	-
P13	Feb-95	5.5	242.0	6.8	0.02	0.48	8.4	4.2	-	-
P14	Feb-95	13.0	216.0	84.0	0.01	0.51	1.7	8.2	-	-
P15	Feb-95	17.0	294.0	16.8	0.20	1.02	1.0	8.4	-	-
P16	Feb-95	38.0	292.0	46.4	0.18	0.52	1.6	15.2	-	-
P18	Feb-95	4.4	283.0	7.0	0.02	0.47	5.6	8.6	-	-
P19	Feb-95	9.1	818.0	9.6	ND	0.55	5.5	3.2	-	-
P20	Feb-95	7.9	933.0	10.2	0.02	0.60	6.2	4.9	-	-
P21	Feb-95	9.0	1231.0	10.6	0.02	0.62	5.8	5.1	-	-
P01	Feb-96	3.8	221.8	2.5	0.02	0.05	8.8	1.7	6.8	5.1
P02	Feb-96	6.2	262.7	3.3	0.02	0.04	8.5	1.1	10.2	13.5
P03	Feb-96	28.1	264.5	22.3	0.02	0.04	8.4	1.0	8.0	10.9
P04	Feb-96	2.7	243.8	2.2	0.02	0.04	8.9	1.3	9.4	11.1
P05	Feb-96	20.9	234.0	17.2	0.02	0.04	8.5	3.3	8.6	13.0
P06	Feb-96	37.1	92.1	22.4	0.07	0.76	9.5	1.2	6.3	9.5
P07	Feb-96	242.0	102.1	11.6	0.04	0.52	8.8	0.7	5.3	6.5
P08	Feb-96	11.4	141.5	8.0	0.02	0.04	6.6	1.1	7.8	5.9
P09	Feb-96	5.4	112.3	5.8	0.02	0.03	7.5	1.1	8.1	6.2
P10	Feb-96	5.6	133.9	4.2	0.02	0.03	7.2	1.2	19.0	6.5
P11	Feb-96	2.1	118.3	2.2	0.02	0.04	7.7	0.4	12.2	4.9
P12	Feb-96	5.0	124.6	3.6	0.01	0.02	8.8	0.5	13.2	0.4
P13	Feb-96	37.4	140.2	41.2	0.01	0.01	8.2	1.0	21.7	7.5
P14	Feb-96	65.8	193.3	73.2	0.02	0.30	5.6	1.6	43.9	15.3
P15	Feb-96	46.4	317.3	26.8	0.10	0.07	4.3	6.8	83.8	20.2
P16	Feb-96	27.3	309.8	21.6	1.40	2.00	7.8	9.3	81.6	16.5
P17	Feb-96	26.7	145.9	21.2	0.02	0.06	8.3	1.3	25.4	8.4
P18	Feb-96	11.7	143.9	8.6	0.40	0.05	7.0	1.9	26.2	7.0
P19	Feb-96	10.5	633.7	8.0	0.02	0.01	7.2	1.0	260.0	15.2
P20	Feb-96	6.8	833.8	9.2	0.02	0.01	7.6	1.1	376.6	17.2
P21	Feb-96	16.6	841.3	8.0	0.02	0.01	7.2	0.6	375.6	18.4
P01	Jun-95	315.0	94.4	162.5	ND	0.20	6.7	3.5	-	-
P02	Jun-95	34.5	202.6	17.6	0.07	0.80	3.8	1.2	-	-
P03	Jun-95	323.0	137.6	195.5	ND	0.60	5.8	4.3	-	-
P04	Jun-95	270.0	163.3	294.8	0.18	1.20	5.9	5.2	-	-
P05	Jun-95	65.0	219.3	64.8	0.07	0.10	6.3	4.3	-	-
P06	Jun-95	27.5	114.0	33.6	ND	0.10	5.9	1.3	-	-
P08	Jun-95	83.0	132.0	76.4	0.04	0.30	5.5	4.0	-	-
P09	Jun-95	5.1	145.0	9.0	0.07	0.10	6.8	1.9	-	-
P10	Jun-95	7.5	196.6	4.6	0.10	0.20	5.6	3.2	-	-
P11	Jun-95	5.3	206.4	1.8	0.07	1.00	4.8	1.2	-	-
P12	Jun-95	10.1	170.1	8.0	ND	0.10	4.2	6.2	-	-
P13	Jun-95	16.8	211.7	18.0	0.02	0.20	4.4	6.6	-	-
P14	Jun-95	32.5	204.0	12.4	0.02	0.10	3.2	2.5	-	-
P15	Jun-95	18.3	378.0	41.0	0.10	1.50	4.9	8.9	-	-
P16	Jun-95	25.0	382.0	25.5	0.14	3.60	1.3	11.5	-	-
P18	Jun-95	11.5	285.8	7.6	0.40	0.20	3.5	2.9	-	-

Appendix 3.3 (cont.)

Site code	Month	Turbi-dity (mg/L)	TDS (mg/L)	TSS (mg/L)	PO4 (mg/L)	NO3 (mg/L)	DO (mg/L)	BOD (mg/L)	Cl (mg/L)	SO4 (mg/L)
P19	Jun-95	87.0	298.0	71.2	ND	0.30	6.3	2.5	-	-
P20	Jun-95	350.0	256.0	116.8	ND	0.20	5.2	4.8	-	-
P21	Jun-95	376	260	122	ND	0.24	4.8	5.2		

Appendix 4.1 Benthic macroinvertebrate individuals sampled by qualitative sampling in the Pong catchment (February 1996) (left and right river banks)

Site	Order	Family	Species	Right	Left	Total
P01	Ephemeroptera	Baetidae	Baetis sp1	10	33	43
P01	Diptera	Ceratopogonidae	Bezzia sp.	2	0	2
P01	Ephemeroptera	Caenidae	Caenis sp2	5	0	5
P01	Diptera	Chironomidae	Chironomidae spp.	7	4	11
P01	Ephemeroptera	Heptagenidae	Heptagenia sp.	0	1	1
P01	Hemiptera	Corixidae	Micronecta sp.	2	9	11
P01	Odonata	Gomphidae	Oliphiogomphus sp.	3	0	3
P01	Odonata	Platycnemididae	Platycnemus sp.	0	1	1
P01	Odonata	Protoneuridae	Protoneuridae sp1	0	1	1
P01	Odonata	Protoneuridae	Protoneuridae sp2	0	1	1
P02	Odonata	Coenagrionidae	Aciagrion sp.	0	2	2
P02	Ephemeroptera	Baetidae	Baetis sp2	0	3	3
P02	Diptera	Ceratopogonidae	Bezzia sp.	1	0	1
P02	Diptera	Chironomidae	Chironomidae spp.	1	1	2
P02	Coleoptera	Gyrinidae	Dineutus sp.	0	4	4
P02	Hemiptera	Gerridae	Metrocoris sp.	1	0	1
P02	Hemiptera	Corixidae	Micronecta sp.	13	0	13
P02	Hemiptera	Notonectidae	Nychia sp.	2	0	2
P02	Odonata	Coenagrionidae	Pseudagrion sp1	0	1	1
P02	Odonata	Coenagrionidae	Pseudagrion sp2	0	1	1
P02	Coleoptera	Gyrinidae	Spanglerogyrus sp.	0	1	1
P03	Ephemeroptera	Baetidae	Baetis sp1	31	6	37
P03	Mollusca	Corbiculidae	Corbicula sp.	1	0	1
P03	Coleoptera	Gyrinidae	Dineutus sp.	1	0	1
P03	Trichoptera	Hydrosychidae	Hydropsyche sp.	0	1	1
P03	Hemiptera	Gerridae	Metrocoris sp.	14	10	24
P03	Odonata	Gomphidae	Oliphiogomphus sp.	1	0	1
P03	Hemiptera	Veliidae	Rhagovelia sp.	1	0	1
P03	Hemiptera	Gerridae	Ventidius sp.	0	2	2
P04	Ephemeroptera	Baetidae	Baetis sp2	2	1	3
P04	Coleoptera	Gyrinidae	Dineutus sp.	0	45	45
P04	Odonata	Libelluliidae	Diplacodes sp.	1	1	2
P04	Odonata	Coenagrionidae	Ischnura sp.	1	0	1
P04	Hemiptera	Gerridae	Limnogonus sp.	0	3	3
P04	Decapoda	Palaemonidae	Macrobrachium lanchestri	2	2	4
P04	Hemiptera	Corixidae	Micronecta sp.	1	0	1
P04	Hemiptera	Notonectidae	Nychia sp.	2	0	2
P04	Odonata	Coenagrionidae	Pseudagrion sp1	3	0	3
P04	Hemiptera	Gerridae	Rhagadotarsus sp1	2	0	2
P04	Odonata	Chlorocyphidae	Rhinocypha sp.	1	0	1
P05	Hemiptera	Gerridae	Cryptobates sp.	4	2	6
P05	Hemiptera	Gerridae	Metrocoris sp.	1	0	1
P05	Hemiptera	Notonectidae	Nychia sp.	1	5	6
P05	Odonata	Coenagrionidae	Pseudagrion sp1	0	1	1
P05	Hemiptera	Gerridae	Rhagadotarsus sp1	8	18	26
P05	Hemiptera	Gerridae	Rhagadotarsus sp2	0	5	5
P05	Coleoptera	Gyrinidae	Spanglerogyrus sp.	0	3	3
P05	Hemiptera	Gerridae	Ventidius sp.	4	3	7

Appendix 4.1 (cont.)

Site	Order	Family	Species	Right	Left	Total
P06	Ephemeroptera	Heptagenidae	Heptagenia sp.	0	1	1
P06	Ephemeroptera	Leptoceridae	Leptocerus sp.	2	5	7
P06	Decapoda	Palaemonidae	Macrobrachium lanchestri	1	0	1
P06	Hemiptera	Veliidae	Macrovelia sp.	1	0	1
P06	Hemiptera	Gerridae	Metrocoris sp.	1	1	2
P06	Hemiptera	Pleiidae	Plea sp.	0	1	1
P06	Hemiptera	Gerridae	Ptilomera sp.	3	0	3
P06	Odonata	Chlorocyphidae	Rhinocypha sp.	1	1	2
P07	Ephemeroptera	Baetidae	Baetis sp2	0	1	1
P07	Hemiptera	Mesoveliidae	Entomovelia	0	2	2
P07	Ephemeroptera	Heptagenidae	Heptagenia sp.	0	1	1
P07	Hemiptera	Hydrometridae	Hydrometra sp.	1	3	4
P07	Hemiptera	Nepidae	Laccotrepes sp.	1	0	1
P07	Ephemeroptera	Leptoceridae	Leptocerus sp.	0	1	1
P07	Decapoda	Palaemonidae	Macrobrachium lanchestri	3	2	5
P07	Hemiptera	Mesoveliidae	Mesovelia sp.	0	2	2
P07	Hemiptera	Notonectidae	Nychia sp.	0	1	1
P07	Hemiptera	Pleidae	Plea sp.	0	2	2
P07	Odonata	Coenagrionidae	Pseudagrion sp1	1	1	2
P07	Hemiptera	Nepidae	Ranatra sp1	1	0	1
P07	Hemiptera	Nepidae	Ranatra sp2	1	0	1
P07	Coleoptera	Gyrinidae	Spanglerogyrus sp.	0	1	1
P07	Hemiptera	Gerridae	Ventidius sp.	0	15	15
P08	Gastopoda	Viviparidae	Anulotaia forcati	0	2	2
P08	Ephemeroptera	Baetidae	Baetis sp2	1	1	2
P08	Diptera	Chironomidae	Chironomidae spp.	0	1	1
P08	Ephemeroptera	Heptagenidae	Heptagenia sp.	4	4	8
P08	Decapoda	Palaemonidae	Macrobrachium lanchestri	1	0	1
P08	Hemiptera	Mesoveliidae	Mesovelia sp.	0	2	2
P08	Hemiptera	Notonectidae	Nychia sp.	1	3	4
P08	Hemiptera	Pleidae	Plea sp.	4	0	4
P08	Hemiptera	Gerridae	Rhagadotarsus sp1	1	1	2
P08	Hemiptera	Gerridae	Rhagadotarsus sp2	1	0	1
P08	Hemiptera	Gerridae	Ventidius sp.	1	0	1
P09	Ephemeroptera	Baetidae	Baetis sp2	1	0	1
P09	Ephemeroptera	Baetidae	Centroptilum sp.	0	1	1
P09	Decapoda	Palaemonidae	Macrobrachium lanchestri	1	3	4
P09	Hemiptera	Gerridae	Rhagadotarsus sp1	1	1	2
P09	Coleoptera	Gyrinidae	Spanglerogyrus sp.	2	2	4
P10	Hemiptera	Gerridae	Amemboa sp.	1	0	1
P10	Ephemeroptera	Baetidae	Baetis sp2	2	11	13
P10	Ephemeroptera	Caenidae	Caenis sp1	1	0	1
P10	Diptera	Chironomidae	Chironomidae spp.	1	1	2
P10	Lepidoptera	Pyralidae	Crambus sp.	1	0	1
P10	Hemiptera	Naucoridae	Ctenipocoris sp.	1	5	6
P10	Gastropoda	Lymnaeidae	Lymnaea sp.	3	1	4
P10	Decapoda	Palaemonidae	Macrobrachium lanchestri	2	40	42
P10	Hemiptera	Corixidae	Micronecta sp.	0	1	1
P10	Hemiptera	Pleiidae	Plea sp.	0	1	1
P10	Odonata	Protoneuridae	Protoneura sp.	0	1	1

Appendix 4.1 (cont.)

Site	Order	Family	Species	Right	Left	Total
P11	Ephemeroptera	Baetidae	Baetis sp2	4	0	4
P11	Diptera	Ceratopogonidae	Bezzia sp.	1	0	1
P11	Ephemeroptera	Caenidae	Caenis sp1	0	2	2
P11	Ephemeroptera	Baetidae	Centroptilum sp.	0	8	8
P11	Diptera	Chironomidae	Chironomidae spp.	7	3	10
P11	Odonata	Libelluliidae	Diplacodes sp.	1	0	1
P11	Decapoda	Palaemonidae	Macrobrachium lanchestri	2	0	2
P11	Hemiptera	Corixidae	Micronecta sp.	1	87	88
P11	Odonata	Libelluliidae	Nanophya sp.	0	1	1
P12	Ephemeroptera	Baetidae	Baetis sp2	19	21	40
P12	Diptera	Ceratopogonidae	Bezzia sp.	0	1	1
P12	Diptera	Chironomidae	Chironomidae spp.	1	0	1
P12	Hemiptera	Naucoridae	Ctenipocoris sp.	1	1	2
P12	Coleoptera	Hydrophilidae	Helobata sp.	0	1	1
P12	Hemiptera	Mesoveliidae	Mesovelia sp.	0	1	1
P12	Hemiptera	Corixidae	Micronecta sp.	2	34	36
P12	Hemiptera	Pleidae	Plea sp.	1	0	1
P12	Hemiptera	Gerridae	Rhagadotarsus sp1	3	4	7
P12	Hemiptera	Gerridae	Rhagadotarsus sp2	13	3	16
P12	Coleoptera	Gyrinidae	Spanglerogyrus sp.	1	0	1
P12	Hemiptera	Gerridae	Ventidius sp.	2	0	2
P13	Diptera	Ceratopogonidae	Bezzia sp.	2	0	2
P13	Diptera	Chironomidae	Chironomidae spp.	1	4	5
P13	Decapoda	Palaemonidae	Macrobrachium lanchestri	7	0	7
P13	Hemiptera	Mesoveliidae	Mesovelia sp.	1	5	6
P13	Hemiptera	Corixidae	Micronecta sp.	3	2	5
P13	Odonata	Protoneuridae	Protoneuridae sp1	15	1	16
P14	Ephemeroptera	Baetidae	Baetis sp2	6	1	7
P14	Diptera	Ceratopogonidae	Bezzia sp.	1	0	1
P14	Ephemeroptera	Caenidae	Caenis sp1	3	0	3
P14	Hemiptera	Nepidae	Cercometus sp.	1	0	1
P14	Diptera	Chironomidae	Chironomidae spp.	5	3	8
P14	Decapoda	Palaemonidae	Macrobrachium lanchestri	4	7	11
P14	Hemiptera	Mesoveliidae	Mesovelia sp.	1	1	2
P14	Hemiptera	Corixidae	Micronecta sp.	11	1	12
P14	Hemiptera	Pleidae	Plea sp.	4	0	4
P14	Odonata	Protoneuridae	Protoneuridae sp1	0	39	39
P14	Odonata	Protoneuridae	Protoneuridae sp2	0	93	93
P14	Hemiptera	Gerridae	Rhagadotarsus sp1	1	0	1
P15	Odonata	Coenagrionidae	Agriocnemis sp1	1	0	1
P15	Odonata	Coenagrionidae	Agriocnemis sp2	1	0	1
P15	Ephemeroptera	Baetidae	Baetis sp2	7	2	9
P15	Diptera	Chironomidae	Chironomidae spp.	8	1	9
P15	Coleoptera	Hydrophilidae	Coelostoma sp.	1	0	1
P15	Hemiptera	Naucoridae	Ctenipocoris sp.	1	0	1
P15	Coleoptera	Hydrophilidae	Halobates sp.	1	0	1
P15	Decapoda	Palaemonidae	Macrobrachium lanchestri	7	0	7
P15	Hemiptera	Mesoveliidae	Mesovelia sp.	0	1	1
P15	Hemiptera	Corixidae	Micronecta sp.	1	5	6

Appendix 4.1 (cont.)

P15	Coleoptera	Noteridae	Noterus sp.	1	1	2
P15	Hemiptera	Notonectidae	Nychia sp.	1	0	1
P15	Coleoptera	Gyrinidae	Spanglerogyrus sp.	0	1	1
P16	Ephemeroptera	Baetidae	Baetis sp2	2	3	5
P16	Hemiptera	Naucoridae	Ctenipocoris sp.	1	0	1
P16	Coleoptera	Hydrophilidae	Helobata sp.	1	0	1
P16	Odonata	Coenagrionidae	Ischnura sp.	5	2	7
P16	Decapoda	Palaemonidae	Macrobrachium lanchestri	0	2	2
P16	Hemiptera	Mesoveliidae	Mesovelia sp.	4	0	4
P16	Hemiptera	Corixidae	Micronecta sp.	4	2	6
P16	Odonata	Coenagrionidae	Pseudagrion sp1	1	1	2
P17	Hemiptera	Gerridae	Rhagadotarsus sp1	27	8	35
P17	Hemiptera	Gerridae	Rhagadotarsus sp2	58	5	63
P17	Hemiptera	Gerridae	Ventidius sp.	13	0	13
P18	Ephemeroptera	Baetidae	Baetis sp1	4	1	5
P18	Hemiptera	Naucoridae	Ctenipocoris sp.	0	1	1
P18	Odonata	Libelluliidae	Hydrobasileus sp.	1	0	1
P18	Hemiptera	Gerridae	Limnogonus sp.	0	1	1
P18	Decapoda	Palaemonidae	Macrobrachium lanchestri	8	8	16
P18	Hemiptera	Mesoveliidae	Mesovelia sp.	0	1	1
P18	Hemiptera	Corixidae	Micronecta sp.	0	2	2
P18	Coleoptera	Noteridae	Noterus sp.	0	1	1
P18	Odonata	Protoneuridae	Protoneuridae sp1	2	1	3
P18	Odonata	Protoneuridae	Protoneuridae sp2	1	0	1
P18	Hemiptera	Gerridae	Rhagadotarsus sp1	0	1	1
P18	Coleoptera	Gyrinidae	Spanglerogyrus sp.	4	0	4
P19	Ephemeroptera	Baetidae	Baetis sp2	4	10	14
P19	Ephemeroptera	Caenidae	Caenis sp1	2	0	2
P19	Decapoda	Palaemonidae	Macrobrachium lanchestri	0	1	1
P19	Hemiptera	Corixidae	Micronecta sp.	2	0	2
P19	Odonata	Coenagrionidae	Pseudagrion sp1	0	4	4
P19	Hemiptera	Gerridae	Rhagadotarsus sp1	0	4	4
P19	Hemiptera	Gerridae	Ventidius sp.	0	2	2
P20	Ephemeroptera	Baetidae	Baetis sp2	0	3	3
P20	Ephemeroptera	Baetidae	Centroptilum sp.	1	0	1
P20	Trichoptera	Leptoceridae	Leptocerus sp.	0	3	3
P20	Decapoda	Palaemonidae	Macrobrachium lanchestri	3	1	4
P20	Hemiptera	Corixidae	Micronecta sp.	1	0	1
P20	Hemiptera	Gerridae	Neogerris sp.	0	1	1
P20	Hemiptera	Pleidae	Plea sp.	1	0	1
P20	Odonata	Coenagrionidae	Pseudagrion sp1	0	1	1
P20	Hemiptera	Gerridae	Rhagadotarsus sp1	0	3	3
P21	Ephemeroptera	Baetidae	Baetis sp2	1	0	1
P21	Diptera	Chironomidae	Chironomidae spp.	0	12	12
P21	Hemiptera	Corixidae	Micronecta sp.	0	6	6
P21	Hemiptera	Pleidae	Plea sp.	1	0	1
P21	Hemiptera	Gerridae	Rhagadotarsus sp1	1	0	1
P21	Hemiptera	Gerridae	Rhagadotarsus sp2	3	0	3

Appendix 4.2 Benthic macroinvertebrate individuals sampled by quantitative sampling in the Pong catchment, six replicates combined (February 1996)

Site	Order	Family	Species	Total
P01	Coleoptera	Elmidae	Cleptelmis sp.	4
P01	Diptera	Ceratopogonidae	Bezzia sp.	9
P01	Diptera	Chironomidae	Chironomidae spp.	44
P01	Diptera	Tipulidae	Limnophila sp.	19
P01	Ephemeroptera	Baetidae	Baetis sp2	7
P01	Ephemeroptera	Caenidae	Caenis sp1	9
P01	Ephemeroptera	Ephemeridae	Ephemera sp.	1
P01	Odonata	Gomphidae	Erpetogomphus sp.	29
P01	Odonata	Libellulidae	Acisoma sp.	1
P01	Odonata	Libellulidae	Diplacodes sp.	1
P01	Trichoptera	Calamoceratidae	Anisocentropus sp.	2
P01	Trichoptera	Hydropsychidae	Cheumatopsyche malaysiensis	6
P01	Trichoptera	Polycentropodidae	Cyrnellus sp.	2
P01	Trichoptera	Psychomyiidae	Tinodes sp.	1
P01	Veneroida	Corbiculidae	Corbicula brandina	6
P02	Coleoptera	Elmidae	Cleptelmis sp.	33
P02	Coleoptera	Elmidae	Stenelmis sp.	18
P02	Coleoptera	Gyrinidae	Dineutus sp.	18
P02	Coleoptera	Hydrophilidae	Berosus sp.	1
P02	Coleoptera	Psephenidae	Eubrianax sp.	1
P02	Decapoda	Palaemonidae	Macrobrachium lanchestri	1
P02	Diptera	Ceratopogonidae	Bezzia sp.	20
P02	Diptera	Chironomidae	Chironomidae spp.	322
P02	Diptera	Tipulidae	Limnophila sp.	1
P02	Ephemeroptera	Baetidae	Baetis sp2	73
P02	Ephemeroptera	Caenidae	Caenis sp1	5
P02	Hemiptera	Corixidae	Tenagobia sp.	4
P02	Hemiptera	Gerridae	Rheumatogonus sp.	28
P02	Odonata	Coenagrionidae	Argiocnemis sp.	1
P02	Odonata	Gomphidae	Erpetogomphus sp.	5
P02	Odonata	Gomphidae	Sieboldius sp.	1
P02	Odonata	Libellulidae	Diplacodes sp.	12
P02	Odonata	Protoneuridae	Prodasineura sp.	1
P02	Oligochaeta	Oligochaeta	Oligochaeta	46
P02	Trichoptera	Hydropsychidae	Cheumatopsyche malaysiensis	36
P02	Trichoptera	Hydropsychidae	Macrostemum similior	12
P02	Trichoptera	Hydroptilidae	Orthotrichia sp	18
P02	Veneroida	Corbiculidae	Corbicula brandina	186

Appendix 4.2 (cont.)

Site	Order	Family	Species	Total
P03	Coleoptera	Dytiscidae	Dytiscus sp.	1
P03	Coleoptera	Dytiscidae	Eretes sp.	1
P03	Coleoptera	Elmidae	Cleptelmis sp.	97
P03	Coleoptera	Elmidae	Stenelmis sp.	9
P03	Coleoptera	Psephenidae	Eubrianax sp.	1
P03	Decapoda	Palaemonidae	Macrobrachium lanchestri	1
P03	Diptera	Ceratopogonidae	Bezzia sp.	7
P03	Diptera	Chironomidae	Chironomidae spp.	33
P03	Diptera	Culicidae	Mimomyia sp.	1
P03	Diptera	Tipulidae	Limnophila sp.	92
P03	Ephemeroptera	Baetidae	Centroptilum sp.	11
P03	Ephemeroptera	Caenidae	Caenis sp1	6
P03	Ephemeroptera	Ephemeridae	Ephemera sp.	5
P03	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	9
P03	Odonata	Gomphidae	Erpetogomphus sp.	28
P03	Odonata	Gomphidae	Labrogomphus sp.	4
P03	Odonata	Libellulidae	Diplacodes sp.	1
P03	Odonata	Protoneuridae	Prodasineura sp.	1
P03	Plecoptera	Perlidae	Phanoperla sp.	3
P03	Trichoptera	Hydropsychidae	Cheumatopsyche malaysiensis	481
P03	Trichoptera	Hydropsychidae	Macrostemum similior	19
P03	Trichoptera	Hydroptilidae	Orthotrichia sp	4
P03	Trichoptera	Leptoceridae	Triaenodes sp.	5
P03	Veneroida	Corbiculidae	Corbicula brandina	24
P04	Decapoda	Palaemonidae	Macrobrachium lanchestri	6
P04	Diptera	Ceratopogonidae	Bezzia sp.	2
P04	Diptera	Chironomidae	Chironomidae spp.	239
P04	Diptera	Tipulidae	Limnophila sp.	1
P04	Ephemeroptera	Baetidae	Baetis sp1	4
P04	Ephemeroptera	Caenidae	Caenis sp1	55
P04	Ephemeroptera	Heptageniidae	Heptagenia sp.	1
P04	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	46
P04	Hemiptera	Corixidae	Palmacorixa sp.	5
P04	Hemiptera	Gerridae	Limnogonus sp.	2
P04	Odonata	Libellulidae	Diplacodes sp.	2
P04	Oligochaeta	Oligochaeta	Oligochaeta	2
P04	Trichoptera	Ecnomidae	Ecnomus sp.	9
P04	Veneroida	Corbiculidae	Corbicula brandina	4
P05	Diptera	Chaoboridae	Chaoborus sp.	199
P05	Diptera	Chironomidae	Chironomidae spp.	11

Appendix 4.2 (cont.)

Site	Order	Family	Species	Total
P05	Ephemeroptera	Ephemeridae	Litobrancha sp.	1
P05	Oligochaeta	Oligochaeta	Oligochaeta	3
P05	Veneroida	Corbiculidae	Corbicula brandina	1
P06	Coleoptera	Elmidae	Stenelmis sp.	1
P06	Coleoptera	Psephenidae	Eubrianax sp.	2
P06	Diptera	Chironomidae	Chironomidae spp.	2
P06	Ephemeroptera	Caenidae	Caenis sp1	2
P06	Trichoptera	Polycentropodidae	Neureclipsis sp.	1
P06	Trichoptera	Polycentropodidae	Polycentropus sp.	2
P07	Coleoptera	Elmidae	Cleptelmis sp.	1
P07	Coleoptera	Elmidae	Stenelmis sp.	8
P07	Coleoptera	Gyrinidae	Dineutus sp.	1
P07	Coleoptera	Psephenidae	Eubrianax sp.	5
P07	Decapoda	Palaemonidae	Macrobrachium lanchestri	9
P07	Diptera	Ceratopogonidae	Bezzia sp.	28
P07	Diptera	Chironomidae	Chironomidae spp.	62
P07	Ephemeroptera	Caenidae	Caenis sp1	15
P07	Ephemeroptera	Ephemeridae	Litobrancha sp.	0
P07	Ephemeroptera	Leptophlebiidae	Choroterpes sp.	14
P07	Oligochaeta	Oligochaeta	Oligochaeta	6
P07	Trichoptera	Ecnomidae	Ecnomus sp.	15
P07	Trichoptera	Polycentropodidae	Polycentropus sp.	4
P08	Coleoptera	Psephenidae	Eubrianax sp.	3
P08	Diptera	Ceratopogonidae	Bezzia sp.	30
P08	Diptera	Chaoboridae	Chaoborus sp.	1
P08	Diptera	Chironomidae	Chironomidae spp.	15
P08	Ephemeroptera	Caenidae	Caenis sp1	3
P08	Oligochaeta	Oligochaeta	Oligochaeta	5
P08	Trichoptera	Ephemeridae	Litobrancha sp.	17
P08	Trichoptera	Polycentropodidae	Neureclipsis sp.	8
P09	Diptera	Ceratopogonidae	Bezzia sp.	4
P09	Diptera	Chironomidae	Chironomidae spp.	310

Appendix 4.2 (cont.)

Site	Order	Family	Species	Total
P09	Ephemeroptera	Caenidae	Caenis sp2	26
P09	Ephemeroptera	Potamanthidae	Potamanthus sp.	16
P09	Odonata	Gomphidae	Hagenius sp.	4
P09	Odonata	Libellulidae	Diplacodes sp.	2
P09	Odonata	Macromiidae	Epophthalmia sp.	1
P09	Oligochaeta	Oligochaeta	Oligochaeta	2
P09	Trichoptera	Ecnomidae	Ecnomus sp.	4
P09	Trichoptera	Polycentropodidae	Phylocentropus sp.	5
P10	Diptera	Ceratopogonidae	Bezzia sp.	4
P10	Diptera	Chaoboridae	Chaoborus sp.	1
P10	Diptera	Chironomidae	Chironomidae spp.	201
P10	Ephemeroptera	Caenidae	Caenis sp2	13
P10	Ephemeroptera	Potamanthidae	Potamanthus sp.	13
P10	Oligochaeta	Oligochaeta	Oligochaeta	1
P10	Trichoptera	Polycentropodidae	Phylocentropus sp.	8
P11	Diptera	Ceratopogonidae	Bezzia sp.	14
P11	Diptera	Chironomidae	Chironomidae spp.	170
P11	Ephemeroptera	Baetidae	Baetis sp2	2
P11	Ephemeroptera	Caenidae	Caenis sp2	23
P11	Odonata	Gomphidae	Sinogomphus sp.	1
P11	Odonata	Libellulidae	Diplacodes sp.	1
P11	Oligochaeta	Oligochaeta	Oligochaeta	4
P11	Trichoptera	Ecnomidae	Ecnomus sp.	1
P11	Trichoptera	Polycentropodidae	Phylocentropus sp.	2
P11	Veneroida	Corbiculidae	Corbicula brandina	14
P12	Decapoda	Palaemonidae	Macrobrachium lanchestri	1
P12	Diptera	Ceratopogonidae	Bezzia sp.	1
P12	Diptera	Chironomidae	Chironomidae spp.	163
P12	Hemiptera	Corixidae	Micronecta sp.	1
P12	Trichoptera	Ecnomidae	Ecnomus sp.	2
P12	Veneroida	Corbiculidae	Corbicula brandina	1
P13	Diptera	Ceratopogonidae	Bezzia sp.	3
P13	Diptera	Chaoboridae	Chaoborus sp.	1
P13	Diptera	Chironomidae	Chironomidae spp.	23
P13	Ephemeroptera	Caenidae	Caenis sp2	1
P14	Diptera	Ceratopogonidae	Bezzia sp.	2
P14	Diptera	Chironomidae	Chironomidae spp.	106

Appendix 4.2 (cont.)

Site	Order	Family	Species	Total
P14	Ephemeroptera	Caenidae	Caenis sp2	18
P14	Oligochaeta	Oligochaeta	Oligochaeta	1
P14	Trichoptera	Ecnomidae	Ecnomus sp.	1
P15	Diptera	Ceratopogonidae	Bezzia sp.	5
P15	Diptera	Chironomidae	Chironomidae spp.	167
P15	Oligochaeta	Oligochaeta	Oligochaeta	2
P15	Veneroida	Corbiculidae	Corbicula brandina	11
P16	Diptera	Chironomidae	Chironomidae spp.	5
P17	Diptera	Ceratopogonidae	Bezzia sp.	4
P17	Diptera	Chironomidae	Chironomidae spp.	21
P17	Ephemeroptera	Caenidae	Caenis sp2	1
P17	Ephemeroptera	Ephemeridae	Litobrancha sp.	8
P17	Oligochaeta	Oligochaeta	Oligochaeta	3
P18	Diptera	Chaoboridae	Chaoborus sp.	7
P18	Diptera	Chironomidae	Chironomidae spp.	5
P18	Oligochaeta	Oligochaeta	Oligochaeta	2
P19	Diptera	Ceratopogonidae	Bezzia sp.	3
P19	Diptera	Chaoboridae	Chaoborus sp.	1
P19	Diptera	Chironomidae	Chironomidae spp.	30
P19	Oligochaeta	Oligochaeta	Oligochaeta	1
P20	Diptera	Ceratopogonidae	Bezzia sp.	1
P20	Diptera	Chaoboridae	Chaoborus sp.	6
P20	Diptera	Chironomidae	Chironomidae spp.	19
P20	Ephemeroptera	Ephemeridae	Litobrancha sp.	2
P20	Oligochaeta	Oligochaeta	Oligochaeta	2
P20	Trichoptera	Polycentropodidae	Phylocentropus sp.	1
P21	Coleoptera	Elmidae	Cleptelmis sp.	1
P21	Diptera	Ceratopogonidae	Bezzia sp.	21
P21	Diptera	Chaoboridae	Chaoborus sp.	3
P21	Diptera	Chironomidae	Chironomidae spp.	28
P21	Veneroida	Corbiculidae	Corbicula brandina	2

Appendix 6.1 Macroinvertebrate species list sampled from the Phukradueng National Park (October 1995, February and May 1996)

Order	Family	Species
Coleoptera	Chrysomelidae	Pyrrhalta sp.
	Curculionidae	Stenopelmus sp.
		Tanysphyrus sp.
	Dryopidae	Dryopidae sp.
	Dytiscidae	Agabus sp.
		Copelatus sp.
		Cybister sp.
		Dytiscus sp.
		Hydaticus sp.
		Hyphydrus sp.
		Laccophilus sp.
		Neptosternus sp.
		Nipponhydrus sp.
	Elmidae	Cleptelmis sp.
		Leptelmis sp.
		Macronychus sp.
		Microcylloepus sp.
		Ordobrevia sp.
		Phanocerus sp.
		Stenelmis sp.
		Zaitzevia sp.
	Gyrinidae	Aulonogyrus sp.
		Dineutus sp.
		Gyretus sp.
		Gyrinus sp.
		Orectochilus sp.
	Hydraenidae	Hydraenidae
	Hydrochidae	Hydrochus sp.
	Hydrophilidae	Ametor sp.
		Berosus sp.
		Hydrobius sp.
		Hydrochara sp.
		Hydrophius sp.
		Laccobius sp.
	Noteridae	Noterus sp.
	Psephenidae	Acneus sp.
	Scirtidae	Elodes sp.?
	Staphylinidae	Staphylinidae
Diptera	Athericidae	Atherix sp.
	Blephariceridae	Blepharicera sp.
		Philorus sp.
	Ceratopogonidae	Atrichopogon sp.
		Bezzia sp.
	Chaoboridae	Chaoborus sp.
	Chironomidae	Chironomidae
	Culicidae	Mimomyia sp.
	Dolichopodidae	Dolichopodidae
	Empididae	Empididae
	Psychodidae	Pericoma sp.
	Simuliidae	Simulium sp.

Appendix 6.1 (cont.)

Order	Family	Species
	Tabanidae	Tabanus sp.
	Tanyderidae	Tanyderidae
	Thaumaleidae	Thaumalea sp.
	Tipulidae	Antocha sp.
		Limnophila sp.
Ephemeroptera	Baetidae	Baetis sp.1
		Baetis sp.2
		Baetis sp.3
		Centroptilum sp.
	Heptageniidae	Heptagenia sp.
		Nixe sp.
	Leptophlebiidae	Choroterpes sp.
		Habrophlebiodes sp.
		Leptophlebia sp.
		Paraleptophlebia sp.
		Thraulodes sp.
Hemiptera	Corixidae	Agraptocorixa sp.
		Micronecta sp.
	Gerridae	Gerris sp.
	Hebridae	Hebridae sp.
		Hebrus sp.
		Timasius sp.
	Mesoveliidae	Mesovelia sp.
	Naucoridae	Ctenipocoris sp.
		Laccocoris sp.
	Nepidae	Ranatra sp.
	Notonectidae	Enithares sp.
		Notonecta sp.
	Pleidae	Neoplea sp.
		Plea sp.
	Veliidae	Microvelia sp.
		Pseudovelia sp.
		Rhagovelia sp.
Lepidoptera	Cossidae	Prionoxystus sp.
	Pyralidae	Eoophyla sp.
		Eristena sp.
		Neoschoenobia sp.
		Paracymoriza sp.
		Petrophila sp.
		Potamomusa sp.
Megaloptera	Corydalidae	Chauliodes sp.
		Neochauliodes sp.
		Nigonia sp.
		Protohermes sp.
	Sialidae	Sialis sp.
Odonata	Aeshnidae	Aeschnophlebia sp.
		Aeshna sp.
		Anaclaeschra sp.
		Oligoaeschna sp.
		Oplonaeschna sp.
		Planaeschna sp.
		Triacnthagyna sp.

Appendix 6.1 (cont.)

Order	Family	Species
	Coenagrionidae	Agriocnemis sp.
		Argia sp.
	Cordulegastridae	Cordulegaster sp.
	Corduliidae	Cordulia sp.
		Davidius sp.
		Somatochlora sp.
	Euphaeidae	Anisopleura sp.
	Gomphidae	Leptogomphus sp.
		Ophiogomphus sp.
		Paragomphus sp.
		Sieboldius sp.
	Lestidae	Lestes sp.
		Sympecma sp.
	Libellulidae	Acisoma sp.
		Libellula sp.
		Macrothemis sp.
		Orthetrum sp.
		Perithemis sp.
		Pseudothemis sp.
		Sympetrum sp.
	Macromiidae	Macromia sp.
Oligochaeta	Oligochaeta	Oligochaeta
Plecoptera	Chloroperlidae	Chloroperlidae
	Nemouridae	Nemoura sp.
		Protonemura sp.
		Zapada sp.
	Perlidae	Neoperla sp.
		Phanoperla sp.
	Perlodidae	Isoperla sp.
	Pteronarcyidae	Pteronarcella sp.
	Taeniopterygidae	Straphopteryx sp.
Trichoptera	Brachycentridae	Adicrophleps sp.
		Brachycentrus sp.
		Micrasema sp.
	Calamoceratidae	Anisocentropus sp.
	Ecnomidae	Ecnomus sp.
	Glossosomatidae	Agapetus sp.
	Goeridae	Goera sp.
		Lithax sp.
	Helicopsychidae	Helicopsyche sp.
	Hydropsychidae	Amphipsyche meridiana
		Ceratopsyche sp.
		Cheumatopsyche malaysiensis
		Cheumatopsyche sp1
		Diplectrona sp.
		Hydropsyche annulata
		Hydropsyche sp1
		Macrostemum fenestratum
		Macrostemum sp1
		Synaptopsyche sp.
	Hydroptilidae	Hydroptila sp.
		Orthotrichia sp.

Appendix 6.1 (cont.)

Order	Family	Species
		Oxyethira sp.
	Lepidostomatidae	Goerodes sp.
		Lepidostoma sp.
	Leptoceridae	Adicella sp.
		Athripsodes sp.
		Ceraclea sp.
		Leptocerus sp.
		Mystacides sp.
		Oecetis sp.
		Setodes sp.
		Triaenodes sp.
	Molannidae	Molanna sp.
	Philopotamidae	Chimarra sp.
		Dolophilodes sp.
	Phryganeidae	Oligostomis sp.
	Phryganopsychidae	Phryganopsyche sp.
	Polycentropodidae	Neureclipsis sp.
		Nyctiophylax sp.
		Phylocentropus sp.
		Polycentropus sp.
	Psychomyiidae	Lype sp.
		Molanotrichia sp.
		Tinodes sp.
	Rhyacophilidae	Rhyacophila sp.
	Sericostomatidae	Sericostoma sp.
	Xiphocentronidae	Xiphocentron sp.

Appendix 6.2 Macroinvertebrate individuals quantitatively sampled from the Phukradueng National Park, six replicates combined (October 1995, February and May 1996)

Site	Date	Order	Species	Total
U01	Feb-96	Diptera	Bezzia sp.	2
			Chironomidae spp.	38
			Dolichopodidae sp.	3
			Empididae sp.	1
		Odonata	Lestes sp.	5
			Sythetrum sp.	2
		Trichoptera	Ecnomus sp.	1
	May-96	Coleoptera	Macronychus sp.	1
		Diptera	Chaoborus sp.	1
			Chironomidae spp.	774
		Odonata	Agriocnemis sp.	1
			Macrothemis sp.	13
		Trichoptera	Ecnomus sp.	9
			Triaenodes sp.	25
U02	Oct-95	Coleoptera	Copelatus sp.	1
			Cybister sp.	4
			Dineutus sp.	3
			Gyretus sp.	1
			Hydaticus sp.	16
			Hyphydrus sp.	6
			Laccobius sp.	62
			Leptelmis sp.	25
			Ordobrevia sp.	57
		Diptera	Antocha sp.	14
			Bezzia sp.	62
			Chironomidae spp.	92
			Simulium sp.	50
			Tanyderidae	1
		Ephemeroptera	Leptophlebia sp.	54
		Hemiptera	Microvelia sp.	3
		Lepidoptera	Eoophyla sp.	1
			Eristena sp.	5
			Potamomusa sp.	64
		Odonata	Aeschnophlebia sp.	6
			Sympetrum sp.	5
		Plecoptera	Chloroperlidae sp.	2
			Nemoura sp.	2
		Trichoptera	Athripsodes sp.	7
			Ceratopsyche sp.	5
			Chimarra sp.	1
			Ecnomus sp.	1
			Goera sp.	31
			Goerodes sp.	1
			Helicopsyche sp.	171
			Hydroptila sp.	568
			Hydrosyche annulata	58

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
		Trichoptera	Lithax sp.	4
			Macrostemum sp.	14
			Micrasema sp.	24
			Molanna sp.	6
			Molanotrichia sp.	32
			Oecetis sp.	6
			Phryganopsyche sp.	2
			Tinodes sp.	62
			Triaenodes sp.	7
	Feb-96	Coleoptera	Acneus sp.	32
			Gyrinus sp.	1
			Hydaticus sp.	2
			Hydraenidae sp.	2
			Hydrochus sp.	14
			Laccobius sp.	16
			Laccophilus sp.	1
			Ordobrevia sp.	4
			Stenelmis sp.	6
		Diptera	Athericidae sp.	1
			Bezzia sp.	5
			Chironomidae spp.	1484
			Limnophila sp.	1
		Ephemeroptera	Baetis sp.4	3
		Hemiptera	Laccocoris sp.	8
			Micronecta sp.	2
			Microvelia sp.	2
			Plea sp.	1
		Lepidoptera	Potamomusa sp.	1
		Magaloptera	Neochauliodes sp.	1
		Odonata	Aeshna sp.	1
			Cordulia sp.	19
			Lestes sp.	8
			Planaeschna sp.	2
			Sythetrum sp.	2
		Trichoptera	Cheumatopsyche sp.	2
			Ecnomus sp.	2
			Goera sp.	217
			Helicopsyche sp.	314
			Lepidostoma sp.	24
			Lype sp.	55
			Micrasema sp.	1
			Molanna sp.	69
			Mystacides sp.	5
			Polycentropus sp.	7
			Rhyacophila sp.	3
	May-96	Coleoptera	Ametor sp.	16
			Cleptelmis sp.	1
			Hydaticus sp.	3

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
			Hydrobius sp.	1
			Laccobius sp.	6
			Macronychus sp.	12
			Ordobrevia sp.	3
		Diptera	Chironomidae spp.	13
			Simulium sp.	98
		Ephemeroptera	Centroptilum sp.	1
		Lepidoptera	Eoophyla sp.	1
		Megaloptera	Nigonia sp.	8
		Odonata	Macrothemis sp.	1
		Trichoptera	Goera sp.	4
			Hydropsyche sp.	159
			Hydroptila sp.	6
			Macrostemum fenestratum	8
			Molanna sp.	2
			Tinodes sp.	4
			Triaenodes sp.	3
U03	Oct-95	Coleoptera	Macronychus sp.	3
			Stenelmis sp.	101
			Zaitzevia sp.	1
		Diptera	Antocha sp.	2
			Bezzia sp.	12
			Chironomidae spp.	10
			Limnophila sp.	3
			Simulium sp.	6
		Ephemeroptera	Baetis sp.2	15
			Baetis sp.3	3
			Habrophlebiodes sp.	10
			Heptagenia sp.	1
			Leptophlebia sp.	19
			Nixe sp.	4
		Hemiptera	Hebridae sp.	1
		Lepidoptera	Paracymoriza sp.	1
			Petrophila sp.	1
		Megaloptera	Chauliodes sp.	4
		Odonata	Anaclaeschra sp.	1
			Perithemis sp.	1
			Sympetrum sp.	1
		Oligochaeta	Oligochaeta	1
		Plecoptera	Nemoura sp.	4
			Neoperla sp.	2
			Pteronarcella sp.	1
		Trichoptera	Ceraclea sp.	1
			Goera sp.	3
			Hydroptila sp.	1
			Lepidostoma sp.	2
			Micrasema sp.	2
			Molanna sp.	2

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
			Orthotrichia sp.	5
			Tinodes sp.	8
	Feb-96	Coleoptera	Acneus sp.	1
			Dytiscus sp.	3
			Gyrinus sp.	4
			Hydaticus sp.	12
			Hydrochus sp.	179
			Hydrophilidae sp.2	18
			Laccobius sp.	39
			Laccophilus sp.	30
			Noterus sp.	1
			Ordobrevia sp.	7
			Orectochilus sp.	2
			Staphylinidae	4
			Stenelmis sp.	26
			Tanysphyrus sp.	6
			Zaitzevia sp.	2
		Diptera	Atherix sp.	2
			Atrichopogon sp.	1
			Bezzia sp.	29
			Chironomidae spp.	434
			Limnophila sp.	23
			Mimomyia sp.	19
			Pericoma sp.	1
			Simulium sp.	1
		Ephemeroptera	Baetis sp.4	20
			Choroterpes sp.	3
			Habrophlebiodes sp.	1
			Leptophlebia sp.	22
			Nixe sp.	19
		Hemiptera	Ctenipocoris sp.	3
			Microvelia sp.	51
			Notonecta sp.	2
			Pseudovelia sp.	23
			Rhagovelia sp.	1
		Lepidoptera	Potamomusa sp.	4
		Magaloptera	Neochauliodes sp.	1
			Protohermes sp.	1
			Sialis sp.	1
		Odonata	Aeschnophlebia sp.	1
			Cordulia sp.	21
			Leptogomphus sp.	1
			Lestes sp.	10
			Planaeschna sp.	1
			Somatochlora sp.	6
		Plecoptera	Nemoura sp.	2
			Neoperla sp.	5
			Phanoperia sp.	1

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
		Trichoptera	Athripsodes sp.	3
			Diplectrona sp.	1
			Ecnomus sp.	17
			Goera sp.	5
			Helicopsyche sp.	1
			Hydropsyche sp.	3
			Hydroptila sp.	4
			Lepidostoma sp.	54
			Lype sp.	25
			Micrasema sp.	38
			Molanna sp.	8
			Mystacides sp.	4
			Polycentropus sp.	37
			Sericostoma sp.	3
	May-96	Coleoptera	Berosus sp.	6
			Cleptelmis sp.	22
			Dineutus sp.	2
			Hydrophius sp.	2
			Laccobius sp.	1
			Macronychus sp.	30
			Ordobrevia sp.	13
			Stenopelmus sp.	1
		Diptera	Antocha sp.	1
			Chironomidae spp.	2
			Simulium sp.	75
		Ephemeroptera	Baetis sp.1	2
			Centroptilum sp.	24
			Heptagenia sp.	4
			Paraleptophlebia sp.	4
		Lepidoptera	Eoophyla sp.	2
		Megaloptera	Nigonia sp.	4
		Odonata	Macrothemis sp.	1
			Microthemis sp.	1
			Sympetrum sp.	1
		Oligochaeta	Oligochaeta	1
		Plecoptera	Nemouria sp.	14
		Trichoptera	Adicella sp.	1
			Adicrophleps sp.	9
			Amphipsyche meridiana	2
			Athripsodes sp.	1
			Chimarra sp.	1
			Ecnomus sp.	3
			Hydroptila sp.	4
			Neureclipsis sp.	1
			Oecetis sp.	14
			Orthotrichia sp.	8
			Triaenodes sp.	2
U04	Oct-95	Coleoptera	Hyphydrus sp.	8

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
			Neptosterus sp.	2
			Nipponhydrous sp.	1
			Ordobrevia sp.	1
		Diptera	Chironomidae spp.	35
			Simulium sp.	3
			Tanyderidae	2
		Ephemeroptera	Baetis sp.1	2
			Leptophlebia sp.	5
			Thraulodes sp.	1
		Hemiptera	Microvelia sp.	1
			Notonecta sp.	1
	-	Lepidoptera	Potamomusa sp.	6
		Odonata	Coenagrionidae sp.	1
			Macromia sp.	1
			Oligoaeschna sp.	2
			Sympetrum sp.	7
		Trichoptera	Anisocentropus sp.	3
			Goera sp.	240
			Goerodes sp.	6
			Helicopsyche sp.	2
			Hydropsyche annulata	1
			Hydroptila sp.	34
			Macrostemum sp.	1
			Microsema sp.	1
			Molanna sp.	22
			Molanotrichia sp.	50
			Oligostomis sp.	1
			Tinodes sp.	9
	Feb-96	Coleoptera	Acneus sp.	348
			Agabus sp.	2
			Copelatus sp.	1
			Dryopidae sp.	3
			Gyrinus sp.	21
			Hydaticus sp.	6
			Hydrochus sp.	18
			Laccobius sp.	215
			Laccophilus sp.	9
			Neptosternus sp.	117
			Nipponhydrous sp.	1
			Noterus sp.	1
			Ordobrevia sp.	1
			Orectochilus sp.	5
			Stenelmis sp.	46
			Tanysphyrus sp.	1
		Diptera	Atrichopogon sp.	1
			Bezzia sp.	64
			Chironomidae spp.	2852
			Limnophila sp.	11

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
			Mimomyia sp.	59
			Simulium sp.	2
			Tabanus sp.	1
		Ephemeroptera	Baetis sp.4	7
			Leptophlebia sp.	33
			Nixe sp.	31
		Hemiptera	Microvelia sp.	17
			Notonecta sp.	2
			Ranatra sp.	1
		Magaloptera	Sialis sp.	3
		Odonata	Cordulia sp.	39
			Davidius sp.	1
			Gomphidae sp3	1
			Lestes sp.	135
			Libellula sp.	3
			Orthetrum sp.	1
			Somatochlora sp.	2
		Plecoptera	Nemoura sp.	2
		Trichoptera	Agapetus sp.	0
			Anisocentropus sp.	18
			Cheumatopsyche sp.	4
			Ecnomus sp.	19
			Goera sp.	143
			Helicopsyche sp.	3
			Hydropsyche sp.	3
			Hydroptila sp.	11
			Lepidostoma sp.	28
			Lype sp.	155
			Macrostermum sp.	1
			Molanna sp.	97
			Mystacides sp.	37
			Polycentropus sp.	24
	May-96	Coleoptera	Ametor sp.	8
			Cleptelmis sp.	14
			Hydaticus sp.	10
			Hydrobius sp.	5
			Laccobius sp.	15
			Macronychus sp.	25
			Neptostemus sp.	1
			Ordobrevia sp.	3
			Phanocerus sp.	1
			Stenelmis sp.	11
		Diptera	Chironomidae spp.	12
			Simulium sp.	147
		Ephemeroptera	Baetis sp.1	7
			Centroptilum sp.	3
			Heptagenia sp.	1
		Hemiptera	Hebrus sp.	4

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
		Lepidoptera	Eoophyla sp.	2
			Prionoxystus sp.	1
		Megaloptera	Nigonia sp.	2
		Trichoptera	Adicrophleps sp.	5
			Hydropsyche sp.	2
			Hydroptila sp.	17
			Molanna sp.	9
			Oxyethira sp.	2
			Tinodes sp.	19
U05	Oct-95	Coleoptera	Dineutus sp.	5
			Laccophilus sp.	2
		Diptera	Blepharicera sp.	1
			Chironomidae spp.	1
			Simulium sp.	34
		Ephemeroptera	Baetis sp.2	8
			Habrophlebiodes sp.	1
		Odonata	Macromia sp.	1
			Ophiogomphus sp.	1
		Plecoptera	Nemoura sp.	1
		Trichoptera	Goera sp.	24
			Hydropsyche sp.	117
			Lepidostoma sp.	1
			Molanna sp.	1
			Oecetis sp.	1
			Tinodes sp.	6
			Xiphocentron sp.	3
	Feb-96	Coleoptera	Acneus sp.	18
			Dytiscus sp.	2
			Gyrinus sp.	2
			Hydaticus sp.	11
			Hydrochus sp.	10
			Laccobius sp.	8
			Laccophilus sp.	22
			Ordobrevia sp.	3
			Stenelmis sp.	5
		Diptera	Bezzia sp.	10
			Chironomidae spp.	1158
			Limnophila sp.	2
		Ephemeroptera	Baetis sp.1	3
			Baetis sp.4	4
			Leptophlebia sp.	24
			Nixe sp.	4
		Hemiptera	Agraptocorixa sp.	2
			Laccocoris sp.	1
		Hemiptera	Micronecta sp.	1
		Magaloptera	Sialis sp.	2
		Odonata	Cordulia sp.	7
			Lestes sp.	17

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
			Macromia sp.	1
			Planaeschna sp.	4
			Somatochlora sp.	2
		Trichoptera	Anisocentropus sp.	7
			Cheumatopsyche sp.	1
			Ecnomus sp.	12
			Goera sp.	133
			Hydroptila sp.	6
			Lepidostoma sp.	50
			Leptocerus sp.	5
			Lype sp.	8
			Molanna sp.	51
			Mystacides sp.	21
			Neureclipsis sp.	1
			Nyctiophylax sp.	3
			Polycentropus sp.	28
			Tinodes sp.	2
			Xiphocentron sp.	1
	May-96	Coleoptera	Ametor sp.	1
			Cleptelmis sp.	4
			Hydaticus sp.	2
			Hydrobius sp.	2
			Macronychus sp.	6
		Diptera	Antocha sp.	1
			Chironomidae spp.	5
			Simulium sp.	341
		Ephemeroptera	Baetis sp.1	4
			Centroptilum sp.	7
			Heptagenia sp.	1
			Paraleptophlebia sp.	1
		Trichoptera	Adicrophleps sp.	1
			Hydropsyche sp.	23
			Tinodes sp.	2
			Triaenodes sp.	3
U06	Feb-96	Coleoptera	Gyrinus sp.	2
			Hydaticus sp.	20
			Hydrochus sp.	4
			Laccobius sp.	5
			Laccophilus sp.	28
			Neptosternus sp.	4
			Ordobrevia sp.	3
			Orectochilus sp.	1
			Staphylinidae	1
			Stenelmis sp.	242
			Tanysphyrus sp.	1
		Diptera	Atherix sp.	2
			Atrichopogon sp.	5

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
			Bezzia sp.	28
			Chironomidae spp.	1782
			Empididae sp.	3
			Limnophila sp.	21
			Mimomyia sp.	4
			Pericoma sp.	1
			Simulium sp.	79
			Thaumalea sp.	10
		Ephemeroptera	Baetis sp.4	96
			Leptophlebia sp.	59
			Nixe sp.	2
		Hemiptera	Gerris sp.	1
			Micronecta sp.	2
			Microvelia sp.	15
			Plea sp.	9
		Lepidoptera	Potamomusa sp.	67
		Magaloptera	Neochauliodes sp.	2
			Sialis sp.	8
		Odonata	Aeshna sp.	4
			Cordulegaster sp.	1
			Cordulia sp.	35
			Gomphidae sp3	1
			Lestes sp.	26
			Libellula sp.	1
			Planaeschna sp.	3
			Somatochlora sp.	5
		Plecoptera	Isoperla sp.	1
			Nemoura sp.	63
			Neoperla sp.	5
			Protonemura sp.	3
		Trichoptera	Agapetus sp.	29
			Cheumatopsyche sp.	5
			Ecnomus sp.	23
			Goera sp.	22
			Hydropsyche sp.	271
			Hydroptila sp.	9
			Lepidostoma sp.	8
			Leptocerus sp.	4
			Lype sp.	82
			Micrasema sp.	107
			Molanna sp.	39
			Mystacides sp.	16
			Polycentropus sp.	56
			Rhyacophila sp.	6
	May-96	Coleoptera	Cleptelmis sp.	10
			Macronychus sp.	14
			Stenelmis sp.	3
		Diptera	Antocha sp.	1

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
			Chironomidae spp.	2
			Philorus sp.	2
			Simulium sp.	254
		Ephemeroptera	Baetis sp.1	31
			Centroptilum sp.	55
			Paraleptophlebia sp.	4
		Odonata	Oplonaeschna sp.	1
		Trichoptera	Brachycentrus sp.	2
			Cheumatopsyche malaysiensis	131
			Ecnomus sp.	1
			Hydroptila sp.	3
			Neureclipsis sp.	1
			Tinodes sp.	9
U07	Oct-95	Coleoptera	Macronychus sp.	8
			Microcylloepus sp.	1
		Diptera	Antocha sp.	38
			Chironomidae spp.	25
			Simulium sp.	307
		Ephemeroptera	Baetis sp.3	21
		Hemiptera	Mesovelia sp.	1
		Odonata	Sympetrum sp.	4
		Plecoptera	Nemoura sp.	22
			Straphopteryx sp.	5
		Trichoptera	Goera sp.	2
			Hydropsyche sp.	2
			Hydroptila sp.	6
			Micrasema sp.	1
			Mystacides sp.	1
			Phylocentropus sp.	1
			Polycentropus sp.	1
			Setodes sp.	1
			Tinodes sp.	16
	Feb-96	Coleoptera	Gyrinus sp.	1
			Hydaticus sp.	20
			Hydrochus sp.	5
			Laccophilus sp.	28
			Ordobrevia sp.	2
			Orectochilus sp.	1
			Stenelmis sp.	148
			Tanysphyrus sp.	1
		Diptera	Athericidae sp.	2
			Bezzia sp.	33
			Chironomidae spp.	1423
			Limnophila sp.	9
			Mimomyia sp.	6
			Simulium sp.	9
			Thaumalea sp.	10
		Ephemeroptera	Baetis sp.4	61

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
			Heptagenia sp.	1
			Leptophlebia sp.	12
			Paraleptophlebia sp.	4
		Hemiptera	Micronecta sp.	2
			Microvelia sp.	1
			Plea sp.	9
		Lepidoptera	Potamomusa sp.	18
		Megaloptera	Neochauliodes sp.	2
			Sialis sp.	8
		Odonata	Aeshna sp.	4
			Cordulia sp.	26
			Lestes sp.	26
	-		Planaeschna sp.	2
			Somatochlora sp.	5
			Sympetrum sp.	1
		Plecoptera	Nemoura sp.	5
			Neoperla sp.	5
		Trichoptera	Athripsodes sp.	2
			Ecnomus sp.	22
			Goera sp.	12
			Hydroptila sp.	9
			Lepidostoma sp.	5
			Leptocerus sp.	9
			Lype sp.	76
			Micrasema sp.	8
			Molanna sp.	18
			Mystacides sp.	7
			Polycentropus sp.	45
			Rhyacophila sp.	6
			Xiphocentron sp.	3
	May-96	Coleoptera	Ametor sp.	2
			Cleptelmis sp.	6
			Macronychus sp.	15
			Ordobrevia sp.	1
		Diptera	Antocha sp.	1
			Chironomidae spp.	1
			Simulium sp.	1225
		Ephemeroptera	Baetis sp.1	4
		Hemiptera	Neoplea sp.	3
		Megaloptera	Nigonia sp.	1
		Odonata	Macrothemis sp.	1
			Triacnthagyna sp.	1
		Oligochaeta	Oligochaeta	1
		Plecoptera	Zapada sp.	4
		Trichoptera	Adicrophleps sp.	1
			Tinodes sp.	7
U08	Feb-96	Coleoptera	Aulonogyrus sp.	5
			Berosus sp.	3

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
			Hydaticus sp.	18
			Hydraenidae sp.	1
			Hydrochus sp.	10
			Hyphydrus sp.	3
			Laccobius sp.	29
			Laccophilus sp.	5
			Ordobrevia sp.	24
			Stenelmis sp.	513
		Diptera	Atrichopogon sp.	3
			Bezzia sp.	14
			Chironomidae spp.	1335
			Empididae sp.	1
			Limnophila sp.	10
			Mimomyia sp.	2
		Ephemeroptera	Baetis sp.4	9
			Leptophlebia sp.	154
			Nixe sp.	21
		Hemiptera	Ctenipocoris sp.	1
			Mesovelia sp.	1
			Micronecta sp.	4
			Microvelia sp.	12
			Plea sp.	1
			Timasius sp.	1
		Lepidoptera	Neoschoenobia sp.	1
			Potamomusa sp.	12
		Magaloptera	Neochauliodes sp.	2
			Sialis sp.	8
		Odonata	Cordulia sp.	9
			Lestes sp.	30
			Planaeschna sp.	5
			Somatochlora sp.	7
			Sympecma sp.	1
		Plecoptera	Nemoura sp.	2
			Neoperla sp.	1
		Trichoptera	Ecnomus sp.	28
			Goera sp.	8
			Hydroptila sp.	1
			Lepidostoma sp.	15
			Lype sp.	202
			Micrasema sp.	24
			Molanna sp.	35
			Mystacides sp.	1
			Polycentropus sp.	64
	May-96	Coleoptera	Ametor sp.	12
			Cleptelmis sp.	16
			Hydrobius sp.	5
			Hydrochara sp.	1
			Macronychus sp.	76

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
			Ordobrevia sp.	1
		Diptera	Chironomidae spp.	4
			Simulium sp.	36
		Ephemeroptera	Baetis sp.1	5
		Hemiptera	Enithares sp.	2
			Hebrus sp.	6
			Neoplea sp.	2
		Lepidoptera	Eoophyla sp.	1
		Plecoptera	Zapada sp.	1
		Trichoptera	Adicrophleps sp.	2
			Hydroptila sp.	2
U09	Feb-96	Coleoptera	Laccobius sp.	2
			Ordobrevia sp.	1
			Stenelmis sp.	32
			Zaitzevia sp.	4
		Diptera	Blephariceridae	1
			Chironomidae spp.	16
			Limnophila sp.	7
			Mimomyia sp.	1
			Pericoma sp.	1
			Simulium sp.	79
			Tabanus sp.	2
		Ephemeroptera	Baetis sp.1	11
			Baetis sp.4	27
			Leptophlebia sp.	1
			Nixe sp.	6
		Hemiptera	Microvelia sp.	4
		Lepidoptera	Potamomusa sp.	6
		Odonata	Acisoma sp.	1
			Anisopleura sp.	3
			Cordulia sp.	2
			Davidius sp.	1
			Pseudothemis sp.	3
			Sieboldius sp.	1
		Plecoptera	Nemoura sp.	27
		Trichoptera	Cheumatopsyche sp.	2
			Hydropsyche sp.	3
			Hydroptila sp.	1
			Lepidostoma sp.	2
			Lype sp.	1
			Micrasema sp.	76
			Molanna sp.	4
			Polycentropus sp.	2
			Synaptopsyche sp.	8
	May-96	Coleoptera	Cleptelmis sp.	20
			Elodes sp.(?)	2
			Macronychus sp.	3
			Pyrrhalta sp.	1

Appendix 6.32 (cont.)

Site	Date	Order	Species	Total
			Stenelmis sp.	4
		Diptera	Antocha sp.	5
			Chironomidae spp.	43
		Ephemeroptera	Baetis sp.1	138
			Centroptilum sp.	19
			Nixe sp.	46
		Odonata	Argia sp.	1
		Trichoptera	Adicrophleps sp.	5
			Brachycentrus sp.	1
			Dolophilodes sp.	4
			Triaenodes sp.	5

Appendix 6.2 (cont.)

Site	Date	Order	Species	Total
			Stenelmis sp.	4
		Diptera	Antocha sp.	5
			Chironomidae spp.	43
		Ephemeroptera	Baetis sp.1	138
			Centroptilum sp.	19
			Nixe sp.	46
		Odonata	Argia sp.	1
		Trichoptera	Adicrophleps sp.	5
			Brachycentrus sp.	1
			Dolophilodes sp.	4
			Triaenodes sp.	5

Appendix 6.3 Macroinvertebrate individuals quantitatively sampled from five different substrates in site U03 in the Phukradueng National Park, six replicated combined (February 1996)

Order	Species	Substrate				
		Bolder	Cobble	Pebble	Gravel	Sand
Coleoptera	Acneus sp.	1	0	0	0	0
	Curcullionidae sp1	2	2	1	1	0
	Dytiscus sp.	3	0	0	0	0
	Gyrinus sp.	0	0	1	0	0
	Hydaticus sp.	3	1	0	0	0
	Hydrochus sp.	90	65	9	3	0
	Hydrophilidae sp3	11	0	0	0	0
	Laccobius sp.	17	3	2	17	0
	Laccophilus sp.	8	1	3	1	0
	Noterus sp.	1	0	0	0	0
-	Ordobrevia sp.	1	0	0	0	0
	Orectochilus sp.	0	0	2	0	0
	Staphylinidae	3	0	1	0	0
	Stenelmis sp.	11	1	1	0	0
	Zaitzevia sp.	1	0	0	1	0
Diptera	Atherix sp.	1	1	0	0	0
	Atrichopogon sp.	1	0	0	0	0
	Bezzia sp.	18	1	2	3	0
	Chironomidae spp.	150	40	32	21	1
	Limnophila sp.	3	0	8	12	0
	Mimomyia sp.	0	3	0	0	0
	Pericoma sp.	1	0	0	0	0
Ephemeroptera	Baetis sp.	0	1	4	1	0
	Habrophlebiodes sp.	1	0	0	0	0
	Leptophlebia sp.	8	4	0	0	1
	Nixe sp.	5	1	6	3	1
Hemiptera	Ctenipocoris sp.	3	0	0	0	0
	Microvelia sp.	43	1	1	0	0
	Notonecta sp.	2	0	0	0	0
	Rhagovelia sp.	1	0	0	0	0
Lepidoptera	Potamomusa sp.	1	0	0	0	0
Magaloptera	Neochauliodes sp.	0	0	0	1	0
	Protohermes sp.	0	0	0	1	0
Odonata	Cordulia sp.	11	0	0	0	0
	Lestes sp.	2	0	0	0	0
	Somatochlora sp.	1	1	1	0	0
Plecoptera	Neoperia sp.	0	0	2	2	0
	Phanoperia sp.	0	1	0	0	0

Appendix 6.3 (cont.)

Order	Species	Substrate				
		Bolder	**Cobble**	**Pebble**	**Gravel**	**Sand**
Trichoptera	Athripsodes sp.	3	0	0	0	0
	Diplectrona sp.	0	0	0	1	0
	Ecnomus sp.	6	6	1	1	0
	Goera sp.	0	0	0	4	0
	Hydroptila sp.	2	2	0	0	0
	Lepidostoma sp.	3	2	6	2	0
	Micrasema sp.	13	3	3	0	0
	Molanna sp.	0	1	2	0	9
	Mystacides sp.	1	2	0	1	0
	Polycentropus sp.	3	12	3	7	1
	Tinodes sp.	3	16	4	0	0
Total		**438**	**171**	**95**	**83**	**13**

Appendix 6.4 Average density of macroinvertebrate individuals quantitatively sampled from four different nutrient-enriched biotopes in site U03, six replicates combined, in the Phukradueng National Park (February 1996)

Order	**Family**	**Species**	**Biotope**			
			Bedrock	**Leaf**	**Moss**	**Root**
Coleoptera	Dryopidae	Dryopidae	0.0	0.0	0.0	48.0
	Dytiscidae	Copelatus sp.	0.0	0.0	0.0	16.0
		Hydaticus sp.	0.0	76.8	32.0	69.3
		Laccophilus sp.	0.0	48.0	0.0	166.4
		Neptosternus sp.	0.0	64.0	0.0	1408.0
	Elmidae	Ordobrevia sp.	0.0	64.0	16.0	0.0
		Stenelmis sp.	64.0	48.0	298.7	138.7
		Zaitzevia sp.	0.0	0.0	64.0	0.0
	Gyrinidae	Gyrinus sp.	0.0	20.0	0.0	53.3
		Orectochilus sp.	0.0	0.0	0.0	16.0
	Hydrochidae	Hydrochus sp.	0.0	208.0	128.0	100.0
	Hydrophilidae	Berosus sp.	0.0	0.0	0.0	16.0
		Hydrophilidae	0.0	0.0	0.0	16.0
		Laccobius sp.	0.0	64.0	1624.0	176.0
	Psephenidae	Acneus sp.	0.0	0.0	48.0	384.0
Diptera	Athericidae	Athericidae	0.0	16.0	0.0	0.0
		Atherix sp.	0.0	0.0	0.0	16.0
	Blephariceridae	Blephariceridae	0.0	0.0	16.0	0.0
	Ceratopogonidae	Atrichopogon sp.	0.0	0.0	0.0	48.0
		Bezzia sp.	0.0	88.0	208.0	77.3
	Chironomidae	Chironomidae	176.0	4365.3	117.3	5127.1
	Culicidae	Mimomyia sp.?	0.0	0.0	16.0	0.0
	Psychodidae	Pericoma sp.?	0.0	0.0	16.0	0.0
	Simuliidae	Simulium sp.	16.0	0.0	632.0	0.0
	Tabanidae	Tabanus sp.	0.0	0.0	24.0	0.0
	Tipulidae	Limnophila sp.	0.0	0.0	112.0	16.0
Ephemeroptera	Baetidae	Baetis sp.	432.0	48.0	120.0	32.0
	Heptageniidae	Nixe sp.	80.0	0.0	32.0	0.0
	Leptophlebiidae	Choroterpes sp.	0.0	32.0	0.0	16.0
		Leptophlebia sp.	0.0	80.0	16.0	66.7
Hemiptera	Corixidae	Agraptocorixa sp.	0.0	16.0	0.0	0.0
	Nepidae	Ranatra sp.	0.0	0.0	0.0	16.0
	Pleidae	Plea sp.	0.0	16.0	0.0	0.0
	Veliidae	Microvelia sp.	0.0	32.0	138.7	16.0
		Pseudovelia sp.	0.0	0.0	368.0	0.0
Lepidoptera	Pyralidae	Potamomusa sp.	0.0	16.0	64.0	16.0
Magaloptera	Corydalidae	Neochauliodes sp.	0.0	0.0	0.0	16.0
	Sialidae	Sialis sp.	0.0	48.0	0.0	16.0
Odonata	Aeshnidae	Aeschnophlebia sp.	0.0	0.0	16.0	0.0
		Aeshna sp.	0.0	64.0	0.0	0.0
		Planaeschna sp.	0.0	24.0	0.0	26.7
	Corduliidae	Cordulia sp.	32.0	56.0	0.0	80.0
		Davidius sp.	16.0	0.0	0.0	0.0
		Somatochlora sp.	0.0	24.0	0.0	32.0
	Euphaeidae	Anisopleura sp.?	0.0	0.0	48.0	0.0
	Gomphidae	Leptogomphus sp.	0.0	0.0	0.0	16.0
		Sieboldius sp.	16.0	0.0	0.0	0.0
	Lestidae	Lestes sp.	0.0	64.0	0.0	216.0
		Sympecma sp.	0.0	0.0	0.0	16.0

Appendix 6.4 (cont.)

Order	Family	Species	Biotope			
			Bedrock	Leaf	Moss	Root
Odonata (cont.)	Libellulidae	Acisoma sp.	16.0	0.0	0.0	0.0
		Libellula sp.	0.0	0.0	0.0	48.0
		Orthetrum sp.	0.0	16.0	0.0	0.0
		Pseudothemis sp.	0.0	0.0	48.0	0.0
		Sympetrum sp.	0.0	0.0	0.0	32.0
Plecoptera	Nemouridae	Nemoura sp.	0.0	0.0	232.0	0.0
	Perlidae	Neoperia sp.	0.0	16.0	0.0	16.0
Trichoptera	Brachycentridae	Micrasema sp.	112.0	32.0	696.0	16.0
	Calamoceratidae	Anisocentropus sp.	0.0	80.0	0.0	0.0
	Ecnomidae	Ecnomus sp.	0.0	58.7	128.0	40.0
	Goeridae	Goera sp.	0.0	32.0	32.0	32.0
	Helicopsychidae	Helicopsyche sp.	0.0	16.0	0.0	968.0
	Hydropsychidae	Cheumatopsyche sp.	0.0	32.0	24.0	32.0
		Hydropsyche sp.	0.0	0.0	48.0	0.0
		Macrostemum sp.	0.0	0.0	16.0	0.0
		Synaptopsyche sp.	0.0	0.0	128.0	0.0
	Hydroptilidae	Hydroptila sp.	16.0	16.0	0.0	32.0
	Lepidostomatidae	Lepidostoma sp.	32.0	170.7	32.0	77.7
	Leptoceridae	Mystacides sp.	0.0	53.3	0.0	152.0
	Molannidae	Molanna sp.	64.0	60.0	0.0	32.0
	Polycentropodidae	Polycentropus sp.	0.0	124.0	56.0	184.0
	Psychomyiidae	Tinodes sp.	16.0	92.8	24.0	138.7
	Rhyacophilidae	Rhyacophila sp.	0.0	16.0	0.0	64.0
	Sericostomatidae	Sericostoma sp.	0.0	0.0	0.0	48.0
	Average density		**14.9**	**87.6**	**77.0**	**142.3**

Appendix 6.5 Benthic macroinvertebrate individuals sampled from riffle and pool areas in site U03 in the Phukradueng National Park, six replicated combined (October 1995)

Order	Family	Species	No. of Individuals		Total
			riffle	pool	
Coleoptera	Elmidae	Macronychus sp.	3	0	3
Coleoptera	Elmidae	Stenelmis sp.	101	0	101
Coleoptera	Elmidae	Zaitzevia sp.	0	1	1
Diptera	Ceratopogonidae	Bezzia sp.	9	3	12
Diptera	Chironomidae	Chironomidae	9	1	10
Diptera	Simuliidae	Simulium sp.	3	3	6
Diptera	Tipulidae	Antocha sp.	2	0	2
Diptera	Tipulidae	Limnophila sp.	0	3	3
Ephemeroptera	Baetidae	Baetis sp.2	15	0	15
Ephemeroptera	Baetidae	Baetis sp.3	0	3	3
Ephemeroptera	Heptagenidae	Heptagenia sp.	0	1	1
Ephemeroptera	Heptagenidae	Nixe sp.	0	4	4
Ephemeroptera	Leptophlebiidae	Habrophlebiodes sp.	10	0	10
Ephemeroptera	Leptophlebiidae	Leptophlebia sp.	0	19	19
Hemiptera	Hebridae	Hebridae sp.	1	0	1
Lepidoptera	Pyralidae	Paracymoriza sp.	0	1	1
Lepidoptera	Pyralidae	Petrophila sp.	1	0	1
Megaloptera	Corydalidae	Chauliodes sp.	0	4	4
Odonata	Aeshnidae	Anaclaeschra sp.	0	1	1
Odonata	Libellulidae	Perithemis sp.	0	1	1
Odonata	Libellulidae	Sympetrum sp.	1	0	1
Oligochaeta	Oligochaeta	Oligochaeta	0	1	1
Plecoptera	Nemouridae	Nemoura sp.	4	0	4
Plecoptera	Perlidae	Neoperla sp.	0	2	2
Plecoptera	Pteronarcyidae	Pteronarcella sp.	0	1	1
Trichoptera	Brachycentridae	Micrasema sp.	2	0	2
Trichoptera	Goeridae	Goera sp.	3	0	3
Trichoptera	Hydroptilidae	Hydroptila sp.	1	0	1
Trichoptera	Hydroptilidae	Orthotrichia sp.	4	1	5
Trichoptera	Lepidostomatidae	Lepidostoma sp.	0	2	2
Trichoptera	Leptoceridae	Ceraclea sp.	1	0	1
Trichoptera	Molannidae	Molanna sp.	0	2	2
Trichoptera	Psychomyiidae	Tinodes sp.	7	1	8
Total			**177**	**55**	**232**

Appendix 6.6 Benthic macroinvertebrate individuals quantitatively sampled from riffle and pool areas in site U02 and U03 in the Phukradueng National Park (October 1995)

Site code	Habitat type	Order	Species	Replicate no. 1	2	3	4	5	6	Total
U02	Riffle	Coleoptera	Dineutus sp.	0	0	0	2	0	1	3
U02	Riffle	Coleoptera	Gyretus sp.	0	0	0	0	0	1	1
U02	Riffle	Coleoptera	Hydaticus sp.	1	5	0	0	6	4	16
U02	Riffle	Coleoptera	Hyphydrus sp.	3	0	0	2	0	0	5
U02	Riffle	Coleoptera	Laccobius sp.	6	11	1	0	16	23	57
U02	Riffle	Coleoptera	Leptelmis sp.	2	16	1	0	1	2	22
U02	Riffle	Coleoptera	Ordobrevia sp.	8	8	5	1	12	6	40
U02	Riffle	Diptera	Antocha sp.	1	1	0	0	1	0	3
U02	Riffle	Diptera	Bezzia sp.	2	6	0	12	0	6	26
U02	Riffle	Diptera	Chironomidae	0	0	0	0	0	8	8
U02	Riffle	Diptera	Simulium sp.	1	2	2	0	25	17	47
U02	Riffle	Diptera	Tanyderidae	0	0	0	0	1	0	1
U02	Riffle	Ephemeroptera	Leptophlebia sp.	17	5	0	4	14	2	42
U02	Riffle	Hemiptera	Microvelia sp.	0	0	0	2	1	0	3
U02	Riffle	Lepidoptera	Eoophyla sp.	0	0	0	0	1	0	1
U02	Riffle	Lepidoptera	Potamomusa sp.	6	6	0	2	7	4	25
U02	Riffle	Odonata	Aeschnophlebia sp.	0	0	0	0	0	6	6
U02	Riffle	Odonata	Sympetrum sp.	0	0	0	1	0	0	1
U02	Riffle	Plecoptera	Nemoura sp.	0	0	0	0	1	1	2
U02	Riffle	Trichoptera	Ceratopsyche sp.	0	0	0	0	2	2	4
U02	Riffle	Trichoptera	Chimarra sp.	0	0	0	0	1	0	1
U02	Riffle	Trichoptera	Goera sp.	1	1	2	3	0	1	8
U02	Riffle	Trichoptera	Helicopsyche sp.	7	22	2	11	3	11	56
U02	Riffle	Trichoptera	Hydropsyche annulata	1	5	10	0	7	31	54
U02	Riffle	Trichoptera	Hydroptila sp.	24	26	0	36	103	9	198
U02	Riffle	Trichoptera	Macrostemum sp.	0	0	0	0	0	14	14
U02	Riffle	Trichoptera	Micrasema sp.	4	1	1	3	1	1	11
U02	Riffle	Trichoptera	Molanna sp.	0	0	0	0	1	0	1
U02	Riffle	Trichoptera	Molanotrichia sp.	0	0	0	2	0	0	2
U02	Riffle	Trichoptera	Oecetis sp.	0	1	0	1	0	1	3
U02	Riffle	Trichoptera	Phryganopsyche sp.	1	0	0	0	0	0	1
U02	Riffle	Trichoptera	Tinodes sp.	0	10	8	0	1	0	19
U02	Riffle	Trichoptera	Triaenodes sp.	3	2	0	0	0	2	7
U02	Pool	Coleoptera	Copelatus sp.	0	1	0	0	0	0	1
U02	Pool	Coleoptera	Cybister sp.	4	0	0	0	0	0	4
U02	Pool	Coleoptera	Hyphydrus sp.	0	0	0	0	0	1	1
U02	Pool	Coleoptera	Laccobius sp.	5	0	0	0	0	0	5
U02	Pool	Coleoptera	Leptelmis sp.	0	0	0	1	1	1	3
U02	Pool	Coleoptera	Ordobrevia sp.	10	1	0	5	0	1	17
U02	Pool	Diptera	Antocha sp.	8	0	0	1	2	0	11
U02	Pool	Diptera	Bezzia sp.	5	0	1	22	0	8	36
U02	Pool	Diptera	Chironomidae	32	0	10	29	11	2	84
U02	Pool	Diptera	Simulium sp.	2	0	0	1	0	0	3
U02	Pool	Ephemeroptera	Leptophlebia sp.	8	0	0	4	0	0	12
U02	Pool	Lepidoptera	Eristena sp.	0	0	0	0	5	0	5
U02	Pool	Lepidoptera	Potamomusa sp.	16	0	2	10	7	4	39
U02	Pool	Odonata	Sympetrum sp.	1	2	1	0	0	0	4
U02	Pool	Plecoptera	Chloroperlidae	2	0	0	0	0	0	2

Appendix 6.6 (cont.)

Site code	Habitat type	Order	Species	Replicate no. 1	2	3	4	5	6	Total
U02	Pool	Trichoptera	Athripsodes sp.	6	0	0	1	0	0	7
U02	Pool	Trichoptera	Ceratopsyche sp.	0	0	0	1	0	0	1
U02	Pool	Trichoptera	Ecnomus sp.	0	0	0	0	1	0	1
U02	Pool	Trichoptera	Goera sp.	4	12	2	2	2	1	23
U02	Pool	Trichoptera	Goerodes sp.	0	0	0	1	0	0	1
U02	Pool	Trichoptera	Helicopsyche sp.	49	6	4	16	10	30	115
U02	Pool	Trichoptera	Hydropsyche annulata	3	0	0	1	0	0	4
U02	Pool	Trichoptera	Hydroptila sp.	216	13	4	98	16	23	370
U02	Pool	Trichoptera	Lithax sp.	0	0	0	3	1	0	4
U02	Pool	Trichoptera	Micrasema sp.	5	2	0	3	2	1	13
U02	Pool	Trichoptera	Molanna sp.	1	0	2	2	0	0	5
U02	Pool	Trichoptera	Molanotrichia sp.	20	10	0	0	0	0	30
U02	Pool	Trichoptera	Oecetis sp.	0	0	0	3	0	0	3
U02	Pool	Trichoptera	Phryganopsyche sp.	0	0	0	0	0	1	1
U02	Pool	Trichoptera	Tinodes sp.	0	12	11	14	6	0	43
U03	Riffle	Coleoptera	Macronychus sp.	2	0	0	0	1	0	3
U03	Riffle	Coleoptera	Stenelmis sp.	0	1	8	56	4	32	101
U03	Riffle	Diptera	Antocha sp.	1	1	0	0	0	0	2
U03	Riffle	Diptera	Bezzia sp.	7	2	0	0	0	0	9
U03	Riffle	Diptera	Chironomidae	7	0	0	0	1	1	9
U03	Riffle	Diptera	Simulium sp.	0	0	0	3	0	0	3
U03	Riffle	Ephemeroptera	Baetis sp.2	1	0	1	0	1	12	15
U03	Riffle	Ephemeroptera	Habrophlebiodes sp.	0	0	1	0	0	0	1
U03	Riffle	Ephemeroptera	Habrophlebiodes sp.	0	0	0	0	8	1	9
U03	Riffle	Hemiptera	Hebridae sp.	0	0	0	0	0	1	1
U03	Riffle	Lepidoptera	Petrophila sp.	0	0	0	1	0	0	1
U03	Riffle	Odonata	Sympetrum sp.	0	0	0	0	1	0	1
U03	Riffle	Plecoptera	Nemoura sp.	0	0	0	1	1	2	4
U03	Riffle	Trichoptera	Ceraclea sp.	0	0	1	0	0	0	1
U03	Riffle	Trichoptera	Goera sp.	0	3	0	0	0	0	3
U03	Riffle	Trichoptera	Hydroptila sp.	1	0	0	0	0	0	1
U03	Riffle	Trichoptera	Micrasema sp.	1	0	0	0	1	0	2
U03	Riffle	Trichoptera	Orthotrichia sp.	3	0	0	0	1	0	4
U03	Riffle	Trichoptera	Tinodes sp.	0	2	2	0	3	0	7
U03	Pool	Coleoptera	Zaitzevia sp.	0	1	0	0	0	0	1
U03	Pool	Diptera	Bezzia sp.	0	0	0	0	3	0	3
U03	Pool	Diptera	Chironomidae	0	0	0	0	1	0	1
U03	Pool	Diptera	Limnophila sp.	0	0	0	0	2	0	2
U03	Pool	Diptera	Limnophila sp.	1	0	0	0	0	0	1
U03	Pool	Diptera	Simulium sp.	0	0	2	0	1	0	3
U03	Pool	Ephemeroptera	Baetis sp.3	0	0	0	0	1	0	1
U03	Pool	Ephemeroptera	Baetis sp.3	1	0	1	0	0	0	2
U03	Pool	Ephemeroptera	Heptagenia sp.	0	1	0	0	0	0	1
U03	Pool	Ephemeroptera	Leptophlebia sp.	2	4	7	0	6	0	19
U03	Pool	Ephemeroptera	Nixe sp.	0	0	4	0	0	0	4
U03	Pool	Lepidoptera	Paracymoriza sp.	0	1	0	0	0	0	1
U03	Pool	Megaloptera	Chauliodes sp.	0	0	2	0	1	1	4
U03	Pool	Odonata	Anaclaeschra sp.	0	1	0	0	0	0	1
U03	Pool	Odonata	Perithemis sp.	0	0	0	0	1	0	1
U03	Pool	Oligochaeta	Oligochaeta	0	0	0	0	1	0	1
U03	Pool	Plecoptera	Neoperla sp.	1	1	0	0	0	0	2
U03	Pool	Plecoptera	Pteronarcella sp.	0	0	0	0	1	0	1

Appendix 6.6 (cont.)

Site code	Habitat type	Order	Species	Replicate no.						Total
				1	2	3	4	5	6	
U03	Pool	Trichoptera	Lepidostoma sp.	0	0	0	0	2	0	2
U03	Pool	Trichoptera	Molanna sp.	1	0	0	0	0	1	2
U03	Pool	Trichoptera	Orthotrichia sp.	1	0	0	0	0	0	1
U03	Pool	Trichoptera	Tinodes sp.	0	0	1	0	0	0	1

Plates 1-201. Benthic fauna from freshwater streams in northeast Thailand.

1 Annelida: Hirudinea: Erpobdellae. 2 Decapoda Palaemonidae *Macrobrachium lanchesteri.* 3 Collembola: Isotomidae: *Isotomurus* sp. 4 Baetidae: *Baetis* sp. 5 Baetidae: *Centroptilum* sp. 6 Baetidae: *Centroptilum* sp. 7 Baetidae. 8 Caenidae: *Brachycercus* sp. 9 Caenidae: *Caenis* sp.1. 10 Caenidae: *Caenis* sp.2. 11 Caenidae: *Caenis* sp. 12 Caenidae. 13 Caenidae. 14 Ephemerellidae: *Serratella* sp. 15 Ephemeridae: *Ephemera* sp. 16 Heptageniidae: *Cinygma* sp. 17 Heptageniidae: *Heptagenia* sp. 18 Heptageniidae *Heptagenia* sp. 19 Heptageniidae: *Leucrocuta* sp. 20 Heptageniidae: *Nixe* sp. 21 Heptageniidae *Nixe* sp. 22 Leptophlebiidae: *Habrophlebiodes* sp. 23 Leptophlebiidae: *Traverella* sp. 24 Leptophlebiidae. 25 Oligoneuriidae: *Isonychia* sp. 26 Polymitarcyidae: *Campsurus* sp. 27 Polymitarcyidae: *Campsurus* sp. 28 Potamanthidae: *Potamanthus* sp. 29 Tricorythidae: *Leptohyphes* sp. 30 Ephemeroptera. 31 Aeshnidae. 32 Chlorocyphidae: *Rhincypha* sp. 33 Chlorolestidae: *Megalestes* sp. 34 Coenagrionidae: *Argriocnemis* sp. 35 Coenagrionidae: *Ischnura* sp. 36 Coenagrionidae: *Pseudogrion* sp. 37 Gomphidae: *Aphylla* sp. 38 Gomphidae: *Hagenius* sp. 39 Gomphidae: *Progomphus* sp. 40 Gomphidae *Progomphus* sp. 41 Gomphidae: *Shaogomphus* sp. 42 Gomphidae: *Sinogomphus* sp. 43 Gomphidae: *Stylogomphus* sp. 44 Gomphidae. 45 Libellulidae: *Diplacodes* sp. 46 Nemouridae: *Amphinemura* sp. 47 Nemouridae: *Mesonemura* sp. or *Indonemura* sp. 48 Nemouridae: *Nemoura* sp. 49 Perlidae: *Calineuria* sp. 50 Perlidae: *Phanoperla* sp. 51 Perlidae. 52 Aphelocheiridae: *Aphelocheirus* sp. 53 Belostomatidae: *Belostoma* sp. 54 Belostomatidae: *Sphaeroderma* sp. 55 Corixidae: *Micronecta* sp. 56 Corixidae: *Palmacorixa* sp. 57 Corixidae: *Sigara* sp. 58 Corixidae: Sigara sp. 59 Corixidae: *Tenagobia* sp. 60 Gerridae: *Amemboa* sp. 61 Gerridae: *Limnogonus* sp. 62 Gerridae: *Neogerris* sp. 63 Gerridae: *Ptilomera* sp. 64 Gerridae: *Rheumatogonus* sp. 65 Gerridae: *Trepobates* sp. 66 Gerridae: *Trepobates* sp.2. 67 Gerridae: *Ventidius modulatus.* 68 Hebridae: *Merragata* sp. 69 Hydrometridae: *Hydrometra Orientalis.* 70 Macroveliidae. 71 Mesoveliidae: *Mesovelia* sp. 72 Naucoridae: *Naucoris scutellaris.* 73 Naucoridae: *Naucoris* sp. 74 Naucoridae: *Pelocoris* sp. 75 Naucoridae: *Pelocoris* sp. 76 Nepidae: *Cercomtus* sp. 77 Notonectidae: *Enithares ciliata.* 78 Notonectidae: *Enithares mandalaynin.* 79 Notonectidae: *Enithares* sp. 80 Notonectidae: *Nichia infuscata.* 81 Pleidae: *Plea* sp. 82 Veliidae: *Rhagovelia* sp.1. 83 Veliidae: *Rhagovelia* sp. 84 Megaloptera: Corydalidae: *Neochauliodes* sp. 85 Corydalidae. 86 Sialidae: *Sialis* sp. 87 Carabidae: *Tachyusa* sp. 88 Curculionidae: *Lixus* sp. 89 Curculionidae: *Stenopelmus* sp. 90 Dytiscidae: *Cybister* sp. 91 Dytiscidae *Deronectes* sp. 92 Dytiscidae: *Deronectes* sp. 93 Dytiscidae: *Dytiscus* sp. 94 Dytiscidae: *Hydaticus* sp. 95 Dytiscidae: *Laccophilus* sp. 96 Dytiscidae: *Neptosternus* sp. 97 Elmidae: *Cleptelmis* sp. 98 Elmidae: *Cleptelmis* sp. 99 Elmidae: *Dubiraphia* sp. 100 Elmidae: *Dubiraphia* sp. 101 Elmidae: *Hexacylloepus* sp. 102 Elmidae: *Neocylloepus* sp. 103 Elmidae: *Stenelmis* sp. 104 Elmidae: *Stenelmis* sp. 105 Elmidae:

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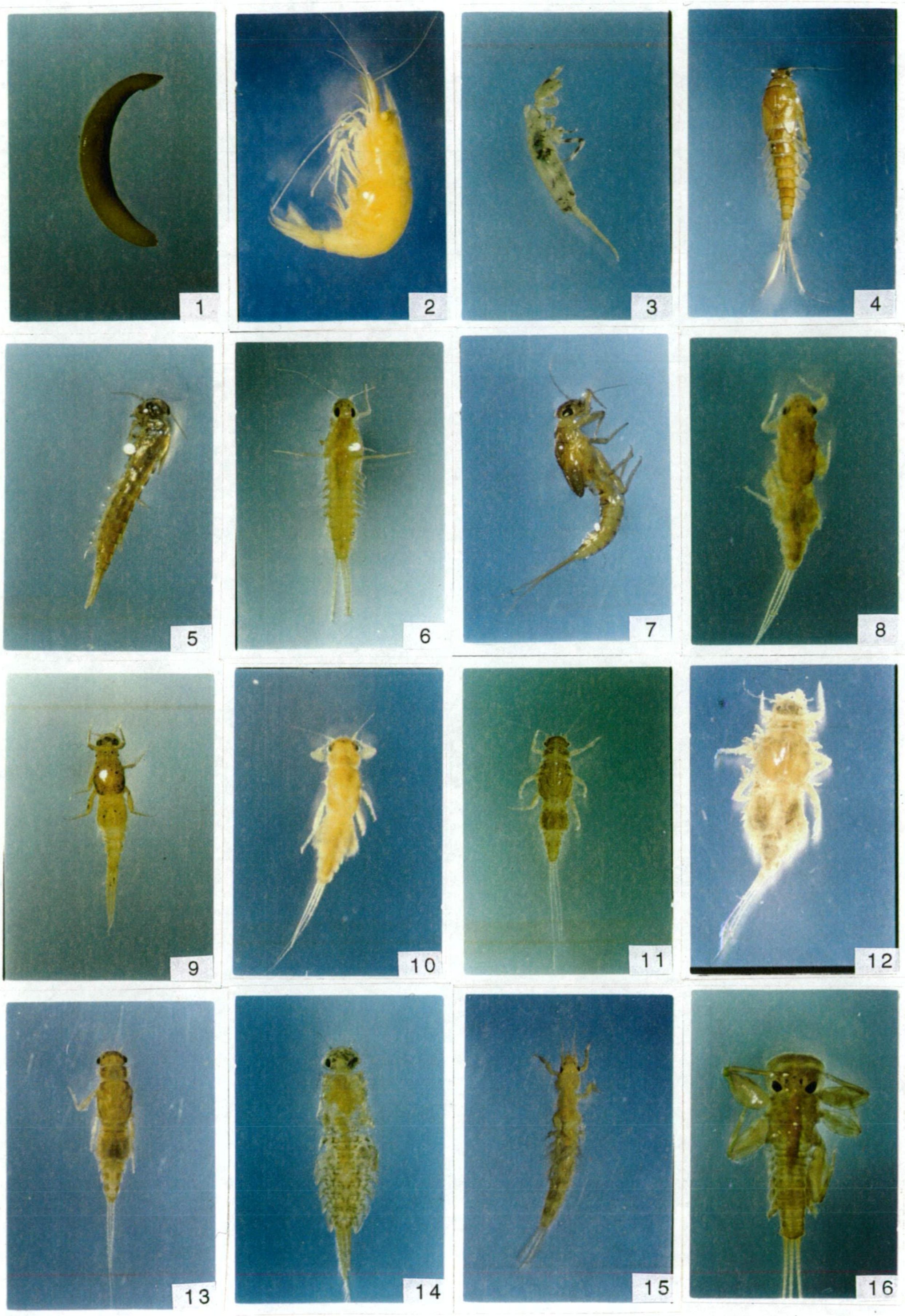
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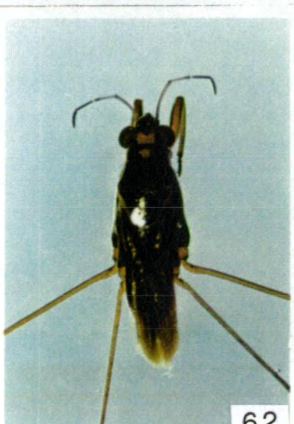
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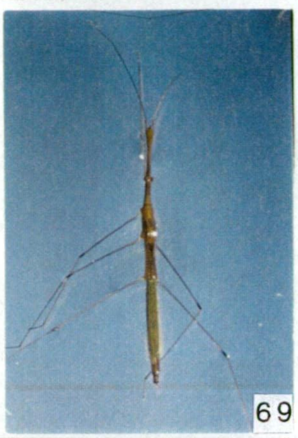
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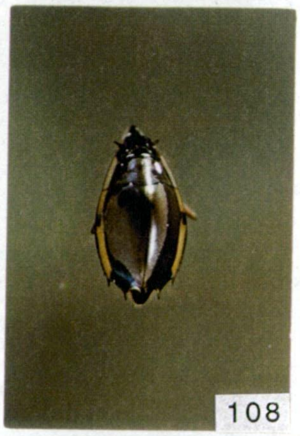
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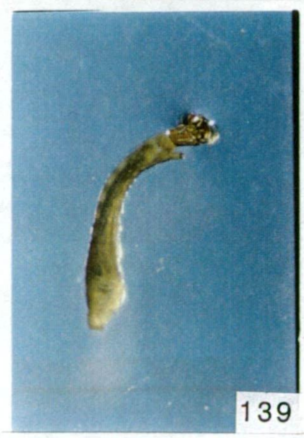
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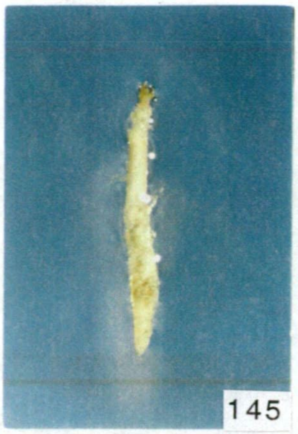
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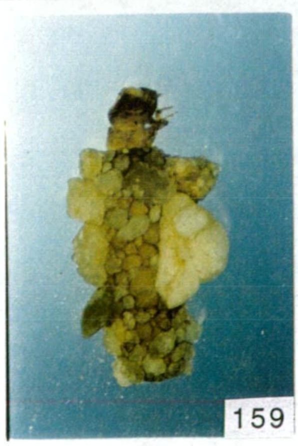
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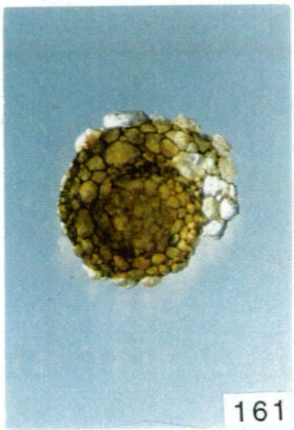
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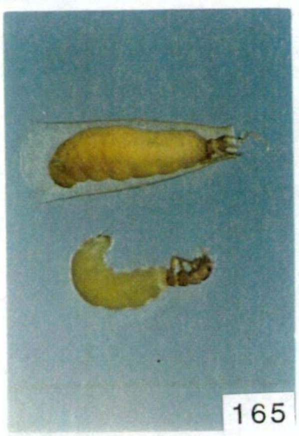
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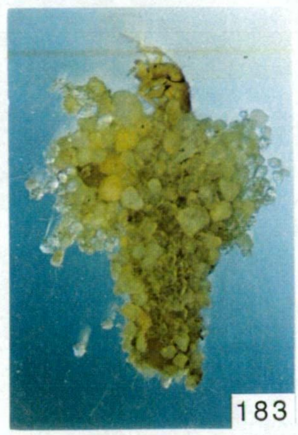
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